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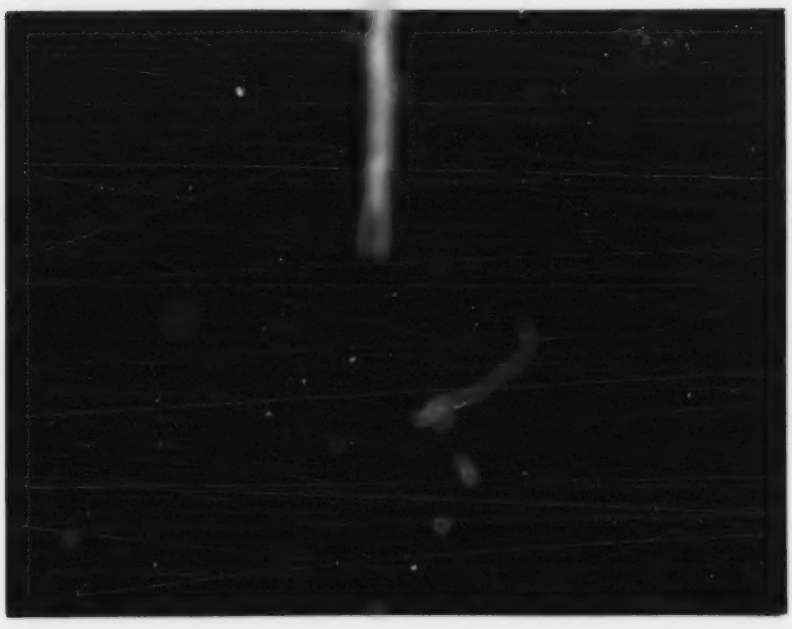

Canada

Manitoba

MG-13087A

ECONOMIC ASSESSMENT AND PREFEASIBILITY STUDIES

ON THE BIRD RIVER CHROMITE DEPOSITS - PHASE IV-A

ADDENDUM : TECHNICAL PROCESS REVIEW

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HATCH ASSOCIATES, LTD.

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HATCH ASSOCIATES LTD.

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November 30, 1988

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EXECUTIVE SUMMARY

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The process for manufacturing stainless steel in Manitoba has been revised to incorporate information received during the market survey that had been completed in March, 1988. The major change from the initial process developed in 1987 for the Phase III study is that the product form is now hot band, a hot rolled strip with a thickness between 2 and 8 millimeters. It was also ascertained that all of the product could be Type 304 stainless steel and that steel scrap should be kept to a minimum.

Since the price of nickel is the dominant cost factor in the manufacture of Type 304 stainless steel, alternative sources have been reviewed. The most promising new source of nickel appears to be the tailings from the Sherritt Gordon operation in Fort Saskatchewan, Alberta. The tailings could also be a major source of iron units and could eliminate the need for steel scrap. The levels of copper contamination in these tailings do not constitute a problem. However up to 85 percent of the nickel would still need to be sourced as Class I material.

After reviewing new technologies in the areas of smelting, casting and hot rolling, it has been established that the most cost-effective approach is to apply modern but conventional designs of submerged arc furnace, slab caster and hot strip mill, and not to incorporate plasma processes or thin slab casting. The recommended process flowsheet includes two 32MW submerged arc furnaces, a 50 tonne Q-BOP steelmaking vessel, a similarly sized AOD refining vessel, slab caster and hot strip mill. Inclusion of the chrome chemicals option will increase the size of the mine and concentrator operation.

A first order capital cost has been estimated at $450 Million (Canadian), with an additional $40 Million (Canadian) for the chrome chemicals option. The direct operating cost to produce Type 304 stainless steel hot band with nickel priced at $6 (Canadian) per pound has been estimated at 60 cents (US) per pound which is known to be competitive with scrap-based steelmaking costs.

1.0 - INTRODUCTION

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Canada Centre for Mineral and Energy Technology, Energy, Mines and Resources, commissioned Hatch Associates to review the technical aspects of the stainless steel process that was developed during the Phase III study and expanded to include hot band production as a result of the Phase IV-A market survey. This work is identified as an addendum to the Phase IV-A work that is part of the Canada-Manitoba Mineral Development Agreement.

This report reviews the four major process areas that impact both capital and operating costs for hot band production. Nickel sources have been investigated in order to identify lower priced materials. The smelting process has been investigated to determine the potential cost savings when employing new technologies. The steelmaking operations have been redefined as a result of the smelting process review and the market survey. The slab casting and hot rolling operation has been developed to identify the most cost-effective and practical alternative system for hot band production.

2.0 - NICKEL SOURCING AND PROCESSING

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Hatch Associates' Phase III report entitled "Economic Assessment and Pre-Feasibility Studies on the Bird River Chromite Deposits" was issued in May 1987. For study purposes, it was assumed that electrolytic nickel from the Inco refinery in Thompson, Manitoba would be available for a stainless steel facility near Winnipeg at a competitive price. At that time, nickel prices were less than $2.00 (US) per pound and several high cost nickel producers had permanently left the industry within the preceding twelve (12) months. In the circumstances, a unit cost of $2.00 (Canadian) per pound of nickel was used for the study.

Reviewing the production costs for type 304 stainless steel in Manitoba that were prepared for the May, 1987 report, nickel represented 45 percent of the direct operating cost of $667 per ton of slab produced. Since then, however, the nickel market has changed dramatically with strong demand and low stockpiles and the price has soared to record levels as shown in Figure 1. While nickel supplied under contract was being delivered during the second quarter of 1988 at prices substantially below the London Metal Exchange (LME) cash price, spot deliveries of primary nickel as well as nickel scrap were available only at these high market prices.

With the stainless steel producers operating at full capacity during 1988, spot nickel demand rose and operating costs increased substantially. Moreover, the cost of production of type 304 stainless steel has risen not only due to nickel costs but also to chromium and steel scrap price increases. Therefore a re-evaluation of the comparative cost between stainless steel produced in Manitoba and scrap-based production in the Pittsburgh area should be undertaken since the prices of steel scrap and chromium in ferroalloys have both doubled while nickel prices have quadrupled. The costs developed for the May, 1987 report therefore do not represent current market conditions and the scrap-based producer price is too low because of undervalued raw materials.

In order to counteract the effect of steep increases in raw material prices, all of the stainless steel producers in the United States instituted escalation factors into their pricing policies such that higher costs have generally been passed on to the consumers of their products. Figure 2 shows the average material surcharge on type 304 stainless steel adopted by all of the flat rolled producers that was introduced for the first time during the fourth quarter of 1987. The surcharge moved up rapidly during the second quarter of 1988 as a result of the nickel price increase. The nickel price downturn of recent weeks has been counterbalanced by a rising chromium price and the surcharge is presently at about 23 cents (US) per pound of 304 stainless steel. Strong demand for 304 stainless has persisted through to the end of the fourth quarter of 1988, and this demand has been reflected in the rising base price which is shown in Figure 3. It will be observed that a part of the surcharge has been converted into the base price. With distributor discounts also being minimized, the net effect has been increased profits to the stainless steel industry. Evidently the pricing mechanisms have been adjusted to prevent stainless steel price erosion as nickel prices fall back to lower levels.

2.1 - Major Nickel Sources in Canada

The major nickel mining areas in Canada are in Manitoba at Thompson and Namew Lake and in Ontario in the Sudbury district. Concentrates produced from these sulfide ores are processed by Inco in Thompson and Sudbury, by Falconbridge in Sudbury and by Sherritt Gordon in Fort Saskatchewan, Alberta. Inco's major products from Thompson and Sudbury are electrolytic nickel, nickel powders, and nickel oxide sinter. Some nickel oxide is also shipped to the Port Colborne facility where utility nickel products are produced. Sherritt Gordon processes concentrates purchased from Inco, Thompson and the Namew Lake operation and produces nickel powders and briquettes. In Sudbury, Falconbridge produces a matte product that is shipped to the refinery in Kristiansand, Norway, for processing into finished nickel products.

Several grades of nickel are used in the manufacture of stainless steel. While individual plants will have their preferences, the alternatives are usually Class I nickel (electrolytic and briquetted powders) and Class II nickel (ferronickel, utility nickel and nickel oxide). When attempting to source primary nickel feed for the stainless steel manufacturing facility in Manitoba, the most obvious sources are electrolytic from Inco, Thompson and briquetted powders from Sherritt Gordon, Fort Saskatchewan.

It was initially thought that lower grades of nickel could also be utilized by expanding the chromium alloy smelter flowsheet. Discussions with Inco have resulted in the understanding that additional nickel sulfide concentrates would not be available. Sherritt Gordon has also been quoted as paying the LME price less refining costs for pentlandite concentrates from Inco, Thompson and the Namew Lake operation so that there is no economic incentive to pursue this approach anyway. Intermediate smelter materials such as converter matte or recycled anodes are possible nickel sources. However, Inco has determined that oxygen enrichment in the converters will enable them to overcome the anode recycle problems that they have been experiencing. In any event, impurity levels in the revert anodes have not been identified and their impact on the steelmaking operation cannot be assessed. In addition, Inco has platinum and gold values in this material which could not leave the processing circuit without incurring some cost penalty. Dead roasted nickel concentrates are another feasible alternative source but Inco is the sole potential supplier of this material and it has been indicated that they would prefer to produce higher value-added products. The dead-roasted concentrate concept could only be seriously considered if the Manitoba project had its own dedicated nickel mine.

A major source, but of unpredictable quantity, would be scrap nickel from the Inco, Thompson refinery. This material generally analyses 99.9 percent nickel but contains impurity levels or physical defects that generally require recycling through the smelter. These impurity levels

may not, however, present any quality problems for flat rolled 304 stainless steel. As an alternative, Sherritt Gordon in Fort Saskatchewan generates approximately 300,000 annual tonnes of tailings, sizing less than 200 mesh, that contain between 40 and 50 percent iron with an average of 1.3 percent nickel. This stockpile has been accumulating since 1956 and is effectively an unlimited source of nickel and iron for the stainless project in Manitoba. In fact, if all of the scrap in the steelmaking flowsheet was replaced by iron oxide from this source, approximately 20 percent of the nickel could also be introduced at the same time. Sherritt Gordon's analyses will be found in Appendix I. Impurities such as sulfur and copper are at levels that will not adversely affect the proposed process or the stainless steel product.

A further potential source of nickel could be ferronickel, an alloy containing 34 to 38 percent nickel with the balance as iron. This material is sold at the LME price of the contained nickel. Even if the iron is given away with the nickel, which is not necessarily the case, the major obstacle to utilizing this material in Manitoba will be the freight charge to Winnipeg since all of the ferronickel producers are located off-shore. The closest ferronickel production facilities are Falconbridge in the Dominican Republic, Inco in Guatemala (which is now shut down) and Cerro Matoso in Colombia. Freight charges would have to be absorbed by the steel plant.

In summary, the most realistic scenario to consider would be to utilize Class I nickel from Inco, Thompson and Sherritt Gordon based on the LME pricing system, any off-grade or scrap nickel from Inco and the tailings available from Sherritt Gordon.

TABLE 2.1

MAJOR NICKEL SOURCES IN CANADA

COMPANY	LOCATION	MAJOR RAW MATERIAL		MAJOR PRODUCT	
		TYPE	SOURCE	TYPE	DESTINATION
Inco	Thompson, Manitoba	Sulfide Ores	Thomspon Area	Electrolytic Nickel	Markets.
Inco	Sudbury, Ontario	Sulfide Ores	Sudbury Area	Nickel Powders Nickel Oxide	Markets. Markets, Port Colborne & Clydach, Wales.
Falconbridge	Sudbury, Ontario	Sulfide Ores	Sudbury, Area	Matte	Kristiansand, Norway, Refinery.
Hudson Bay Mining & Smelting/ Outokumpu Joint Venture	Namew Lake, Manitoba	Sulfide Ores	Namew Lake, Manitoba	Sulfide Concentrates	Sherritt Gordon, Fort Saskatchewan & Outokumpu, in Finland.
Sherritt Gordon	Fort Saskatchewan, Alberta	High Grade Pentlandite Concentrates	Thompson Area Namew Lake, Manitoba	Nickel Powders	Markets.
Inco	Port Colborne, Ontario	Nickel Oxide	Copper Cliff Smelter	Utility Nickel	Markets.

FIGURE 1 : AVERAGE LME NICKEL CASH PRICE

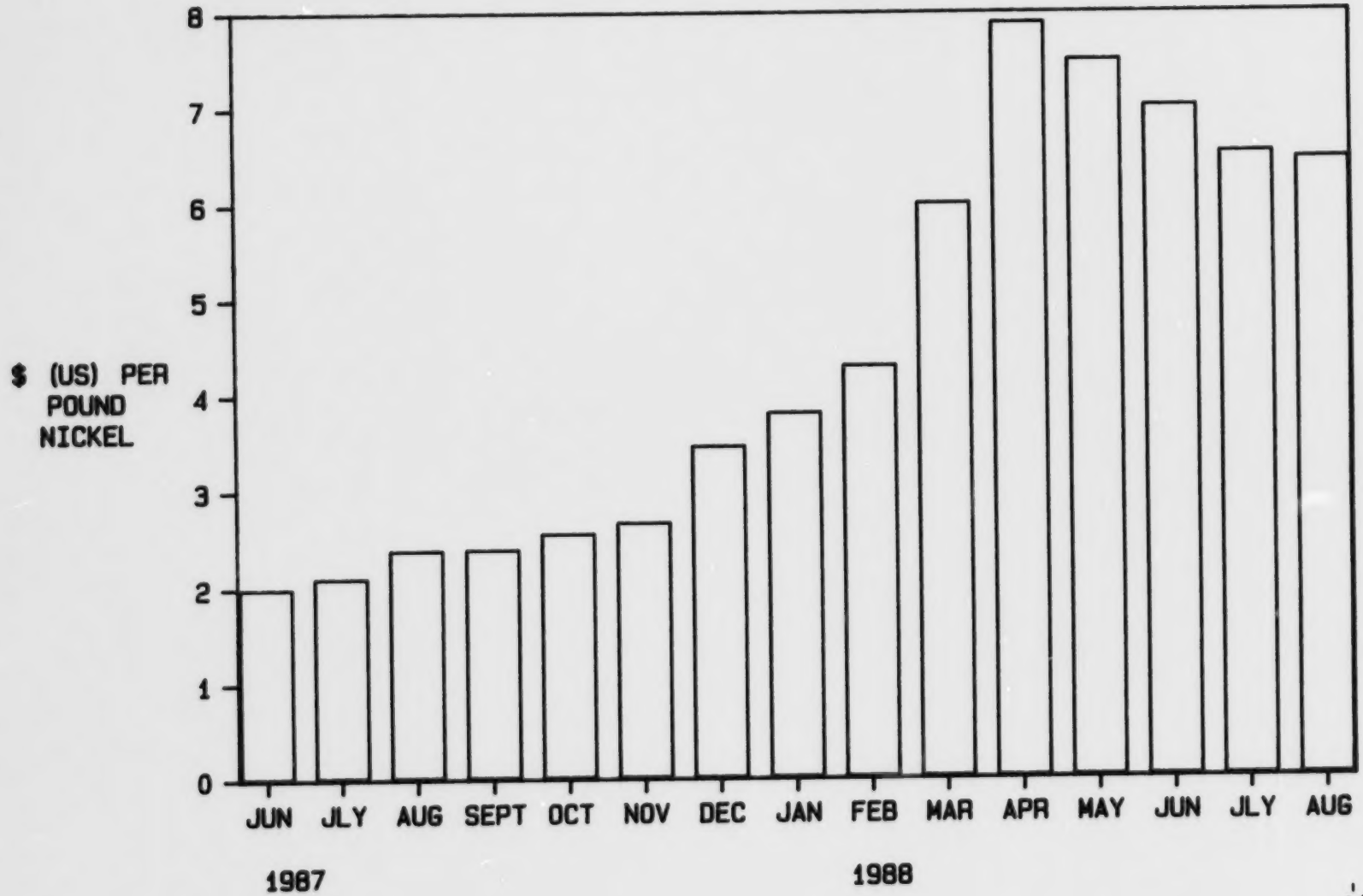


FIGURE 2 : 304 STAINLESS STEEL FLAT PRODUCTS RAW MATERIAL SURCHARGE

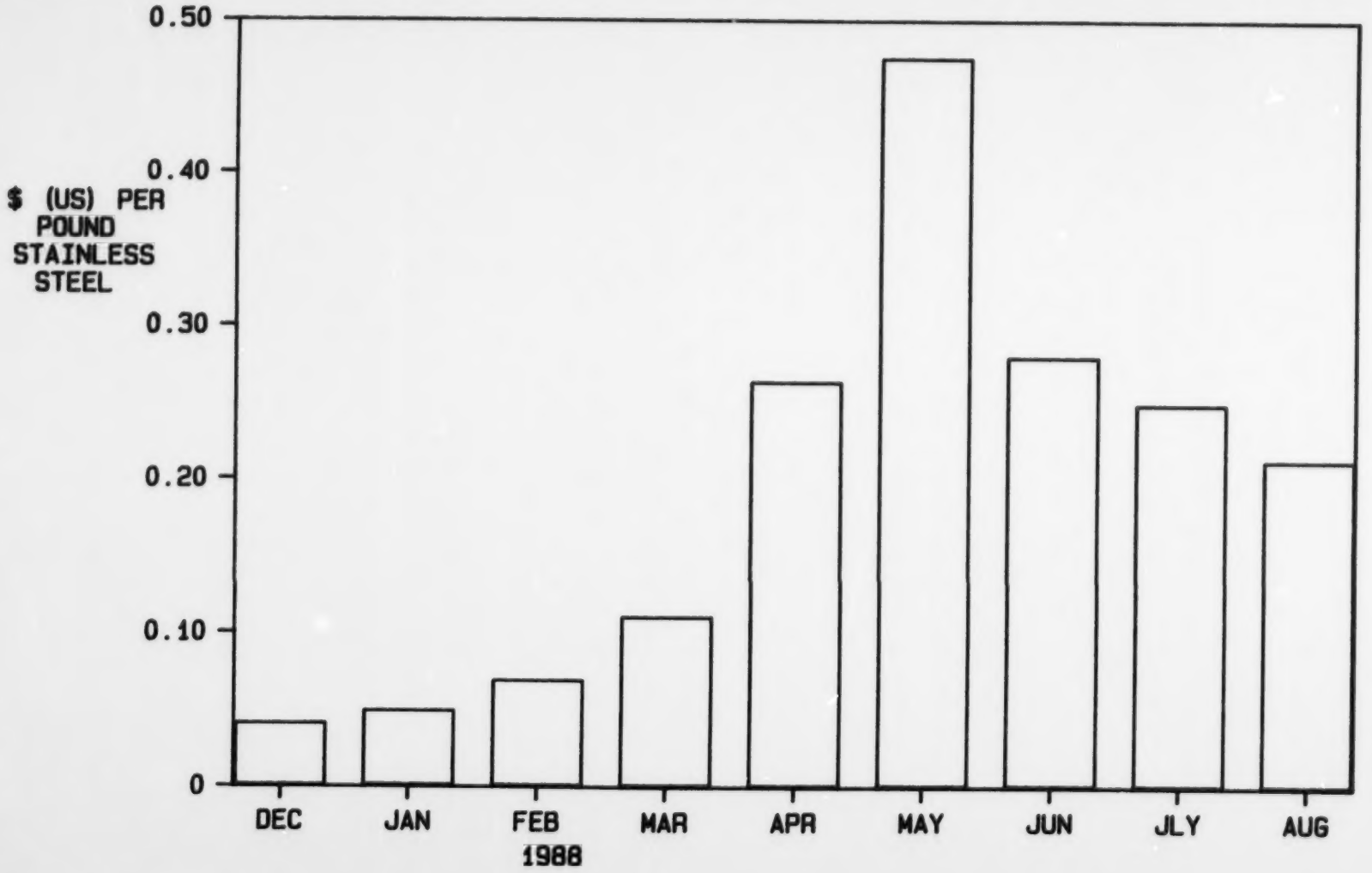
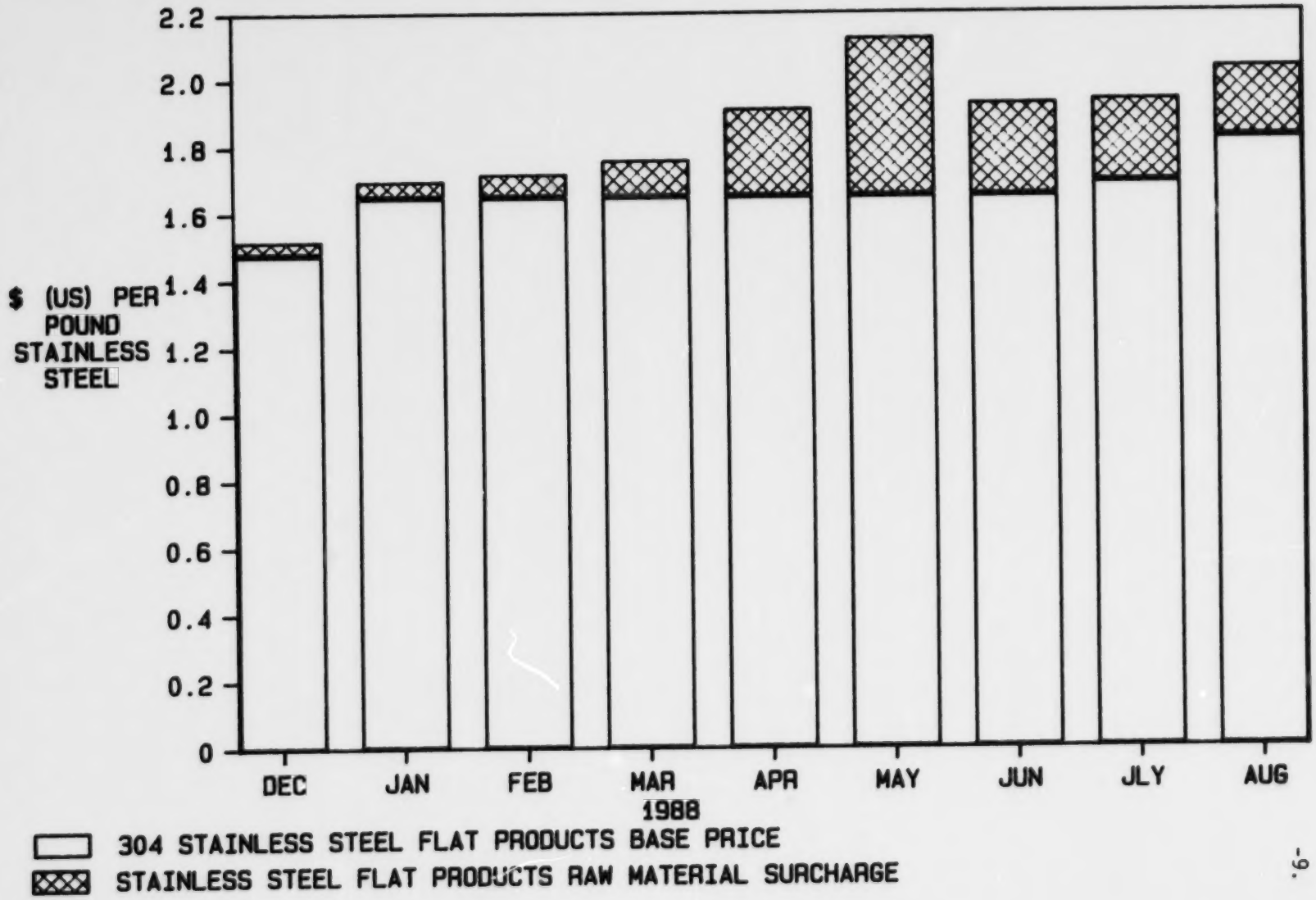


FIGURE 3 : PUBLISHED 304 STAINLESS STEEL FLAT PRODUCTS PRICE



3.0 - SMELTING PROCESS

3.0 - SMELTING PROCESS

The process concept for the Bird River chromite concentrates that was developed for the May, 1987 report incorporated standard smelting furnace technology with no preheating of the raw materials. This approach was considered to be technically secure and required no projections based on optimistic operating data prepared by equipment or process vendors. However, there have been several process developments in the 1980s that should be evaluated in more detail in order to identify those that may have particular advantages to offer to the stainless steel project in Manitoba. These alternatives are known by the names of the companies that have done the development work and have been listed in Table 3.1.

The submerged arc furnace is the standard for the industry and the general outlines are shown in Figure 4. The major engineering effort over the years has been in the development of larger furnaces and there is one unit now operating in Sweden at up to 60 MW with 105 MVA of connected transformer capacity. Another refinement to the process has been the development of semi-closed and closed furnaces, a move which results in the ability to collect and utilize the off-gases which are usually equivalent to a medium calorific value fuel. As physical access to the furnace has been reduced, raw material size preparation has become more important because external means of promoting uniformity of operation are not possible, and this has resulted in several process developments.

There are many commercial operations that are unable to purchase sized ores on a regular basis with the result that agglomeration techniques such as sintering, briquetting and pelletizing are all used on a commercial basis in the manufacture of chromium ferroalloys as shown in Figure 5. Preheating of these raw materials lowers electric power usage, while pre-reduction or solid-state metallization is an additional refinement that further lowers direct operating costs. While agglomeration improves

the performance of the process, the operation becomes more complex and the process savings do not always justify the increased operating costs. This fact has lead to the series of furnace developments that have been identified in Table 3.1. These developments have attempted to avoid the need to agglomerate the chrome ore while maintaining the high efficiencies of operation achieved in the more modern submerged arc furnaces.

The Direct Current (DC) arc furnace was the first commercial development to utilize unagglomerated fine-sized chrome ores. Middelburg Steel and Alloys (MS&A) of South Africa converted a small submerged arc furnace into a single electrode DC furnace and a schematic design is shown in Figure 6. The essential physical differences between this furnace and the submerged arc furnace are that (1) a single 22 inch diameter graphite electrode is utilized and fine ore is introduced through a channel in the center of the electrode and (2) a magnesia lining is used in place of carbon. The electrical design work was completed by ASEA in Sweden and the 12 MW furnace was started up in late 1984. By 1986, the furnace parameters had been generally well defined, but the process economics did not appear to be very favorable, mainly because of the low chromium recovery that was being achieved. Most recent developments at MS&A include an upgrade of this furnace but no new installations.

SKF of Sweden has been promoting its group of plasma-based processes for several years after piloting a 6 MW gas reforming unit used for the direct reduction of iron ore. The SKF furnace design, as shown in Figure 7, is a vertical shaft with plasma burners arranged around the base. This arrangement is conceptually similar to the tuyeres in a blast furnace and is therefore quite different to the submerged arc furnace. The first commercial development known as ScanDust, which started up in 1985, includes an 18 MW furnace designed to process electric furnace baghouse dust into recyclable metal products. By December, 1987, a second commercial plant had been started up, this time to manufacture

ferrochrome. This plant known as SwedeChrome and located in Malmo, Sweden, operates two 24 MW furnaces. For this development, furnace size represented a 30 percent scale-up from the ScanDust installation. The fact that only a maximum of 40 percent of rated capacity was reached during 1988, a time of strong chromium market conditions, has been attributed to significant equipment problems at SwedeChrome.

Tetronics has developed an alternative design of plasma furnace using a transferred arc mode of operation which is illustrated in Figure 8. (MS&A's initial plans in the early 1980s had included the Tetronics furnace, but the change to ASEA was made for the first commercial venture away from the submerged arc furnace.) Tetronics has tested several chrome ores in their pilot plant and claims to have obtained high chromium recoveries, albeit at an electric power usage higher than that of the submerged arc furnace. Commercial successes have been achieved by Tetronics on a small scale with melting and smelting furnaces in operation at power ratings between 1 and 4 MW. Tetronics concedes that their transferred arc plasma furnace could not be scaled up to 20 MW at this time. Therefore this furnace design could only be used for the stainless steel project in Manitoba if multiple units were employed which is not a cost-effective approach.

The Kawasaki Smelting Reduction Process is a Japanese development that has been based upon the use of low grade coke instead of electric power because of the structure of local energy costs. The principal features of the furnace, as shown in Figure 9, include a pre-reduction furnace and a shaft furnace for smelting of the chromite ore into a ferrochrome alloy. The process also includes a coke oven operation and two stages of tuyeres that impinge on the coke bed in the shaft furnace. The process has been tested on a 10 tonne per day pilot plant and the published technical literature indicates a degree of success in producing an iron-chromium-nickel alloy such that a demonstration plant is expected to be

built within the next two years. However the need for a coke plant combined with the early development status of the process itself indicates that this concept cannot be considered at this time for inclusion in the smelter flowsheet for Manitoba.

3.1 - Smelter Capacity

The smelting process that has been developed includes the conversion of chromite concentrates together with some other feed materials containing iron oxides to replace the scrap steel that is generally not available in significant quantities in the Winnipeg area. The flowsheet revisions developed for Hatch Associates' March, 1988 report indicated that 175,000 annual tonnes of chromite concentrates would be needed under alternative No. 1 and 260,000 annual tonnes under alternative No. 2 as shown in Table 3.2. Since it has been established that nickel concentrates would not be available, Sherritt Gordon tailings could be a viable alternative to consider as a source of both nickel and iron units. Modified raw material requirements are shown in Table 3.3 when utilizing the Sherritt Gordon tailings with and without the magnetic concentrates. Provided they are competitively priced, the Sherritt Gordon tailings are the preferable source of iron units because of the associated nickel, and therefore magnetic concentrates have been deleted from consideration for the present time. The chrome chemicals option presented as alternative No. 5 in Table 3.3 utilizes less of the Sherritt Gordon tailings than alternative No. 4 but again introduces an additional saleable product. During the smelting of the Bird River concentrates and Sherritt Gordon tailings, 188,000 annual tonnes of molten iron-chrome-nickel alloy will be produced at a rate of 23 tonnes per hour.

3.2 - Electric Power Usage

The electric power requirement to produce a grade of iron alloy containing up to 19 percent chromium with 1.1 to 1.6 percent nickel has been estimated at 2,800 kWh per tonne of alloy when using a standard submerged

arc furnace. A pair of 32 MW standard submerged arc furnaces would be a commercially proven arrangement to consider. When reviewing the options, Kawasaki and Tetronics are not even close to the required furnace capacity. The DC furnace at MS&A is being scaled up to 20 MW while SKF has commercialized 24 MW plasma furnaces. Therefore more than two furnaces would be needed for these two processing options which are presented in Table 3.4. The SKF plasma furnace operation is 10 percent less energy efficient than the submerged arc furnace and as such an electric power usage of 3,100 kWh per tonne of alloy should be anticipated. The open bath smelting arrangement in the DC arc furnace results in even higher thermal losses and therefore a usage of 3,300 kWh per tonne of alloy is estimated.

3.3 - Iron Sources

The two major sources of iron that have been identified are the magnetic concentrates from the Bird River Chromite flowsheet and the tailings from Sherritt Gordon's Fort Saskatchewan operation. The fact that the tailings contain a significant quantity of nickel suggests that this material should be the preferred source for iron units. As shown in Table 3.3, the difference in nickel availability between alternative Nos. 3 and 4 is 800 annual tonnes, equivalent to 5.5 percent of total nickel demand at the steel plant. Under present market conditions, this quantity of nickel has a value of $10 million (Canadian). At any discount to the LME price, the use of these tailings thus represents a significant savings to the steelmaking process such that Alternative No. 4 will be used for all comparative cost studies between smelting processes.

3.4 - Smelting Costs

Since almost all of the iron will be smelted in the same furnace as the chromium, 188,000 annual tonnes of this alloy will be produced. Therefore the cost comparison between the standard submerged arc furnace, SKF

plasma and the DC arc furnace will be influenced to some extent by economies of scale. As indicated in Table 3.4, two submerged arc furnaces would have the equivalent capacity of three commercial-sized SKF furnaces or four commercial-sized DC arc furnaces. Details on the operating costs will be found in Appendix II and summarized in Table 3.5 for the materials identified as needed for Alternative No. 4. The same alloy cost may be applied for alternative No. 5 since the only major differences are that more Class I nickel will be needed during the steelmaking operation and the furnaces will produce more slag per unit of molten iron-chrome-nickel alloy. Raw material costs are higher for the standard submerged arc furnace because of the requirements for pelletizing. Unagglomerated fines can be used for the SKF Plasma and DC arc furnaces. Reductant usage is lower when coke can be replaced by coal which is generally the case for the plasma and DC arc processes.

A major difference in costs has to do with the means of delivering the electric power to the furnace. The submerged arc furnace utilizes three Soderberg or self-baking electrodes and this arrangement is generally the lowest-cost alternative. The DC arc furnace employs one graphite electrode. While graphite usage per MWh of power will be lower than paste usage in a three electrode furnace, the cost of the graphite is substantially higher than the cost of Soderberg paste such that annual costs will increase overall. The plasma burners have had a lease cost assigned to them, the preferred SKF marketing approach.

Electric power usage is higher for plasma and DC operations, due to thermal inefficiencies of these furnaces. The DC arc furnace is almost an open-bath operation while submerged arc and SKF plasma utilize the energy more efficiently. Labor and supplies cost less for the submerged arc furnace alternative mainly because of economies of scale.

Under the assumption that some scale-up is possible, a 35 MW SKF plasma furnace will be 40 percent larger than the existing 24 MW furnaces at SwedeChrome. This new size could probably be engineered by either installing a fifth plasma burner or running four burners at a higher power rating. Thus two 35 MW SKF furnaces could be an alternative to two 32 MW submerged arc furnaces. Allowing the same scale-up factor, three 25 MW DC arc furnaces could also be an alternative to two 32 MW submerged arc furnaces. Operating cost savings will be gained by these possible economies of scale. However, increased electric power costs completely overwhelm the modest savings gained by not needing to pelletize the raw materials and by switching from coke to coal.

In the circumstances, there do not appear to be any financial incentives to utilize new furnace technologies for the proposed stainless steel plant in Manitoba and two 32 MW submerged arc furnaces will be incorporated into the proposed flowsheet. Additionally, pre-reduction and pre-heating of the charge to the furnace are possible additional refinements. Pre-reduction equipment is capital intensive and this option is often reserved for locations such as Japan where power costs are high. Preheating can be accomplished fairly economically and may result in a savings in electric energy.

TABLE 3.1

ALTERNATIVE SMELTING PROCESSES

FURNACE TYPE:	Standard Submerged Arc	SKF Plasma	ASEA DC	Kawasaki Process	Tetronics Plasma
MAJOR ENERGY SOURCE:	Electric Power	Electric Power	Electric Power	Coal	Electric Power
STATUS OF PROCESS:	Commercial	Commercial	Commercial	Pilot Plant	Commercial
MAXIMUM FURNACE SIZE:	60 MW	24 MW	12 MW	Not Relevant	3 MW

TABLE 3.2
RAW MATERIAL REQUIREMENTS AND PRODUCTS
(Units: annual tonnes)

	Chrome Ore	Chromite Concentrates	Sodium Dichromate Dihydrate Crystals	Chromite Tailings	Magnetic Concentrates	Nickel Concentrates	304 Hot Band
ALTERNATIVE NO. 1							
Total	1,260,000	175,000	--	--	44,000	--	180,000
Chromium	--	35,000	--	--	200	--	32,000
Nickel	--	--	--	--	--	14,500	14,500
Iron	--	42,000	--	--	24,000	> 14,500	131,000
ALTERNATIVE NO. 2							
Total	1,870,000	260,000	45,000	230,000	65,000	--	180,000
Chromium	--	53,300	15,700	36,600	400	--	32,000
Nickel	--	--	--	--	--	--	14,500
Iron	--	62,400	--	60,000	35,700	> 14,500	131,000

Source: Hatch Associates March, 1988 report, page 35.

TABLE 3.3
REVISED RAW MATERIAL REQUIREMENTS AND PRODUCTS
(Units: annual tonnes)

	Chrome Ore	Chromite Concentrates	Magnetic Concentrates	Sodium Dichomate Dihydrate Crystals	Chromite Tailings	Sherritt Gordon Tailings	Molten Iron - Chrome Nickel Alloy	Class I Nickel	304 Hot Band
ALTERNATIVE NO. 3									
Total	1,260,000	175,000	44,000	--	--	160,000	183,000	--	180,000
Chromium	--	35,000	200	--	--	--	33,500	--	32,000
Nickel	--	--	--	--	--	2,000	2,000	12,500	14,500
Iron	--	42,000	23,000	--	--	70,000	133,000	--	131,000
ALTERNATIVE NO. 4									
Total	1,260,000	175,000	--	--	--	215,000	188,000	--	180,000
Chromium	--	35,000	--	--	--	--	33,500	--	32,000
Nickel	--	--	--	--	--	2,800	2,800	11,700	14,500
Iron	--	42,000	--	--	--	96,000	136,000	--	131,000
ALTERNATIVE NO. 5									
Total	1,870,000	260,000	--	45,000	230,000	164,000	188,000	--	180,000
Chromium	--	53,300	--	15,700	36,600	--	33,500	--	32,000
Nickel	--	--	--	--	--	2,100	2,100	12,400	14,500
Iron	--	62,400	--	--	60,000	78,000	136,000	--	131,000

TABLE 3.4

FURNACE ARRANGEMENT OPTIONS

	STANDARD SUBMERGED ARC	SKF PLASMA	DC ARC FURNACE
No. of Furnaces	2	3	4
Power Rating per Furnace	32 MW	22 MW	16 MW
Charge Pretreatment	None	None	None

TABLE 3.5

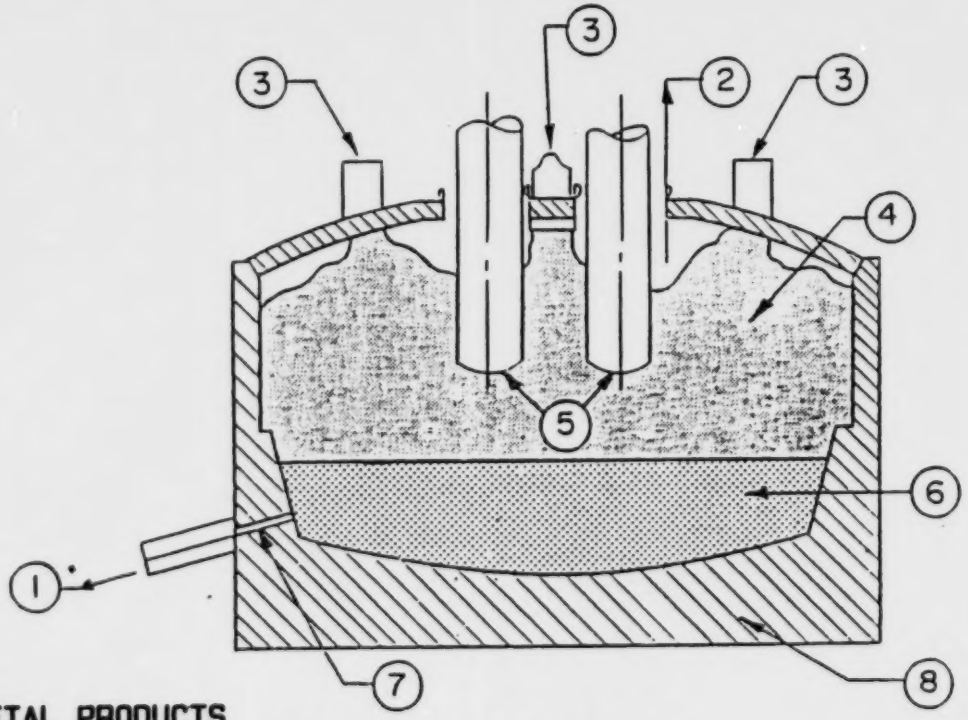
COST COMPARISON OF COMMERCIAL SMELTING

FURNACE ALTERNATIVES FOR MANITOBA

BASIS: $ (CANADIAN) PER TONNE MOLTEN IRON-CHROMIUM-NICKEL ALLOY

	STANDARD SUBMERGED ARC FURNACE	SKF PLASMA FURNACE	DC ARC FURNACE
Raw Materials	228.11	224.78	224.78
Reductants	77.30	70.54	70.27
Electrodes/Plasma	5.51	27.02	17.84
Electric Power	67.71	74.97	79.91
Labor and Supplies	51.82	69.96	93.28
TOTAL:	430.45	467.27	486.08

FIGURE 4 : TYPICAL CROSS SECTION THROUGH A SUBMERGED ARC SMELTING FURNACE PRODUCING CHROMIUM FERROALLOYS



1. SLAG AND METAL PRODUCTS
2. REACTION PRODUCT GASES, DUST, FUME AND VAPORS.
3. ENTRY FOR BLENDED RAW MATERIALS
4. SOLID RAW MATERIAL BURDEN.
5. ELECTRODES SUBMERGED IN BURDEN.
6. MOLTEN METAL AND SLAG.
7. TAPHOLE.
8. REFACTORY LINING.

FIGURE 5 : PROCESS ROUTES EMPLOYED IN THE PRODUCTION OF CHROMIUM FERROALLOYS

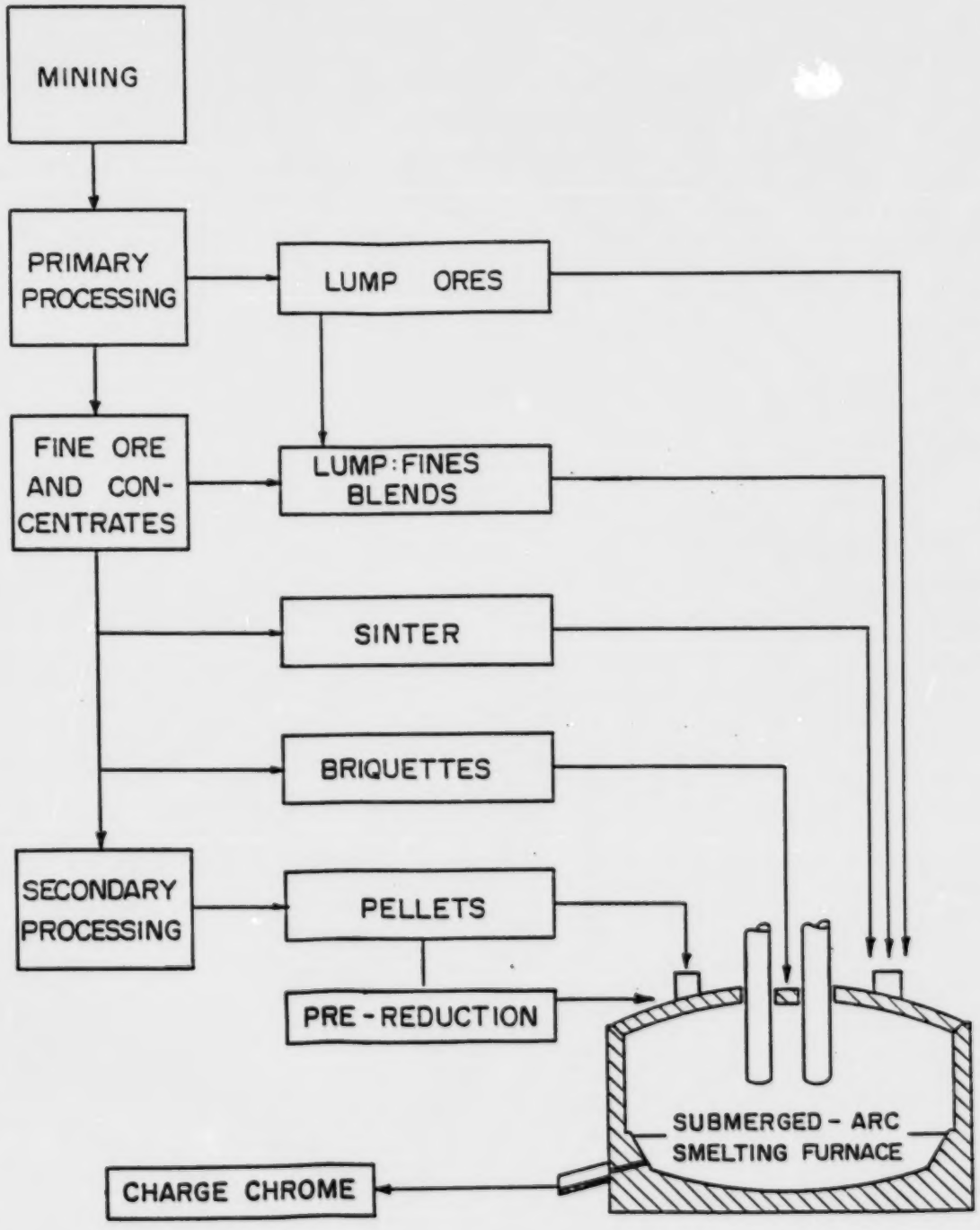


FIGURE 6 : DC ARC FURNACE FOR REDUCTION OF CHROME ORE FINES

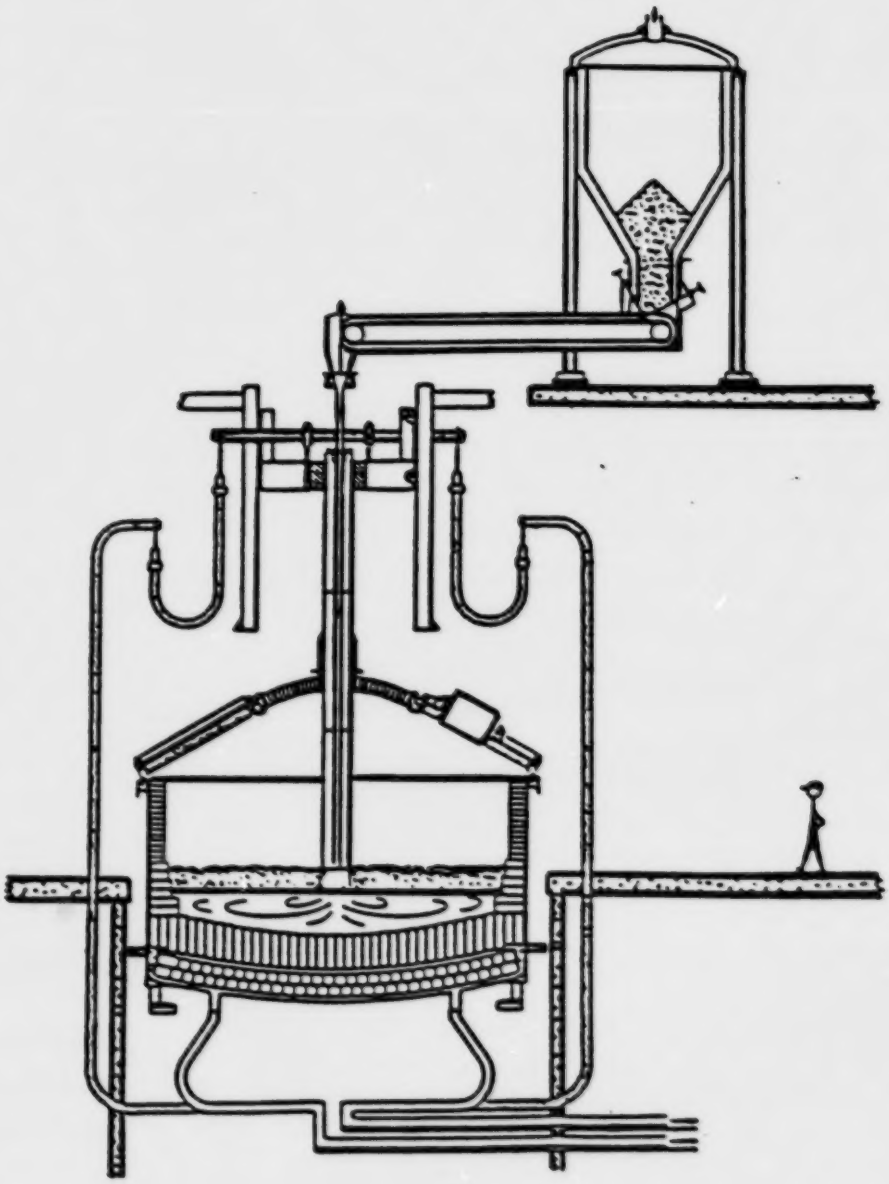


FIGURE 7 :

SKF PLASMA PROCESS AT SWEDECHROME

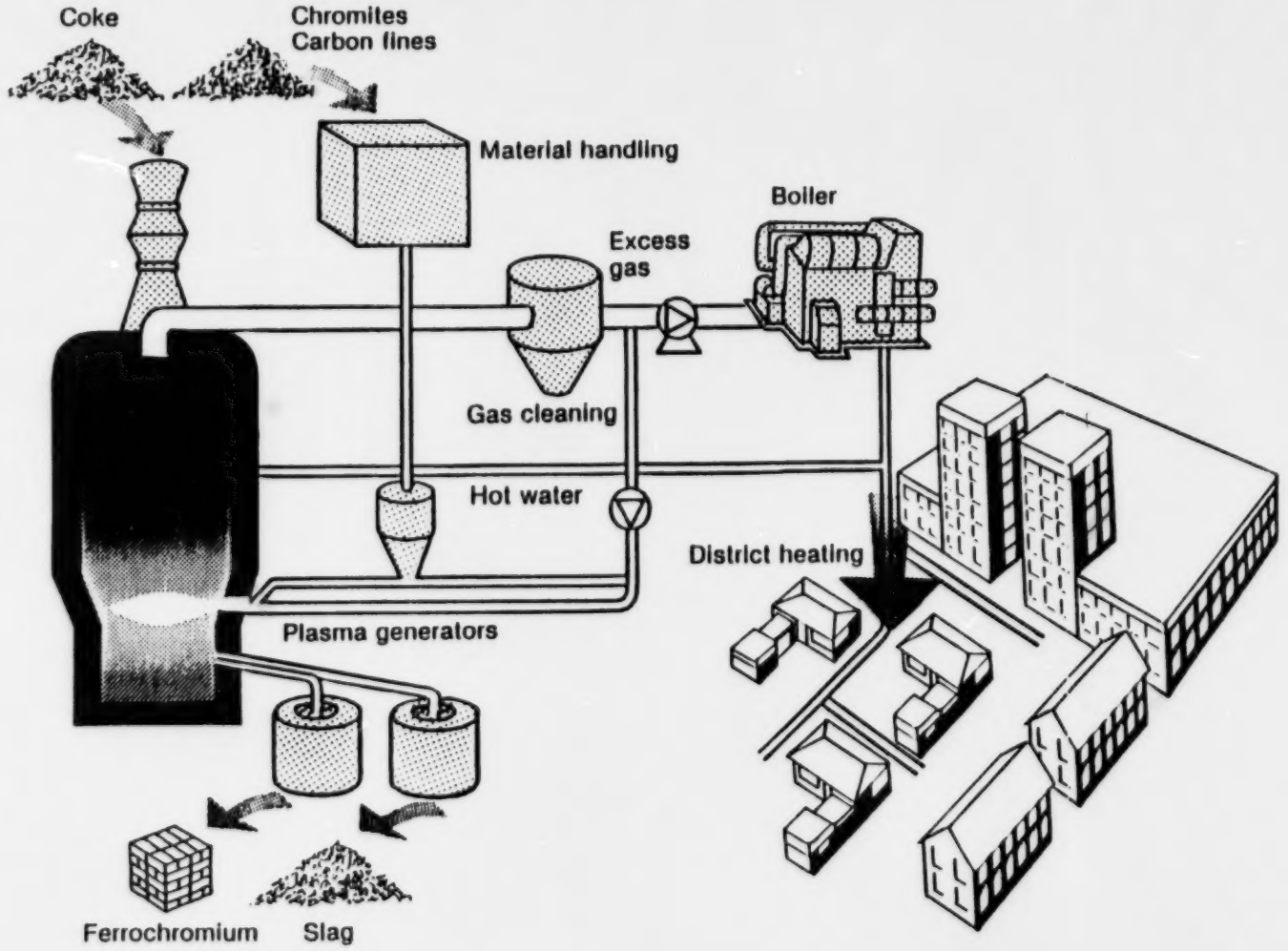


FIGURE 8 :

TETRONICS PLASMA FURNACE

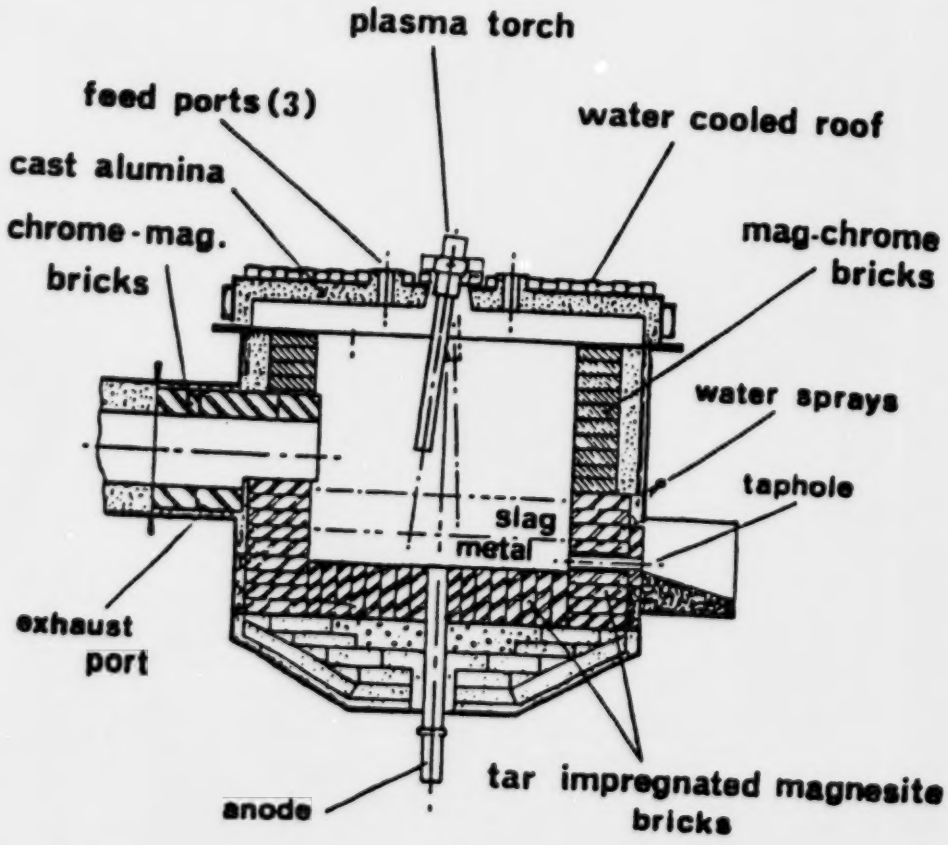
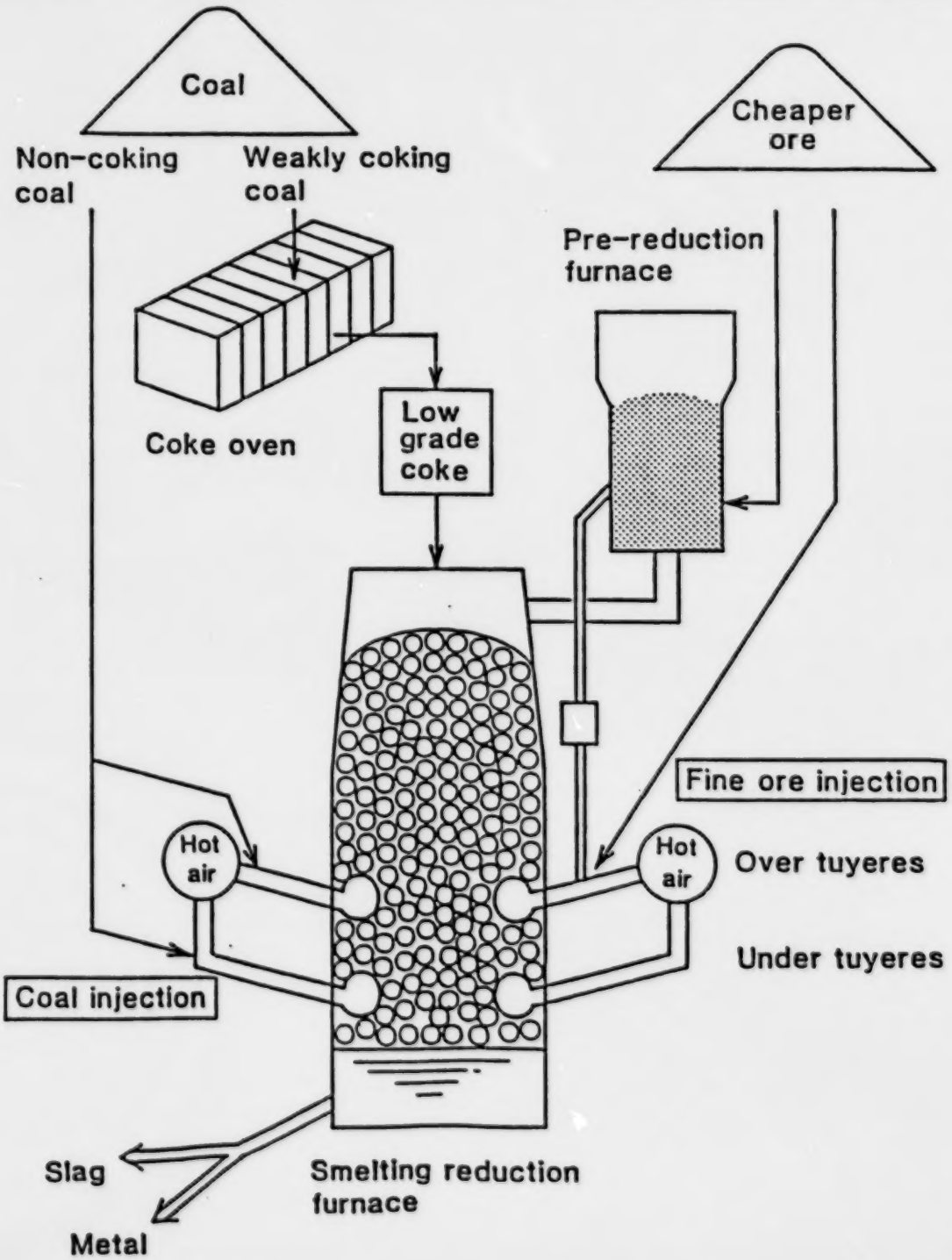


FIGURE 9 : KAWASAKI SMELTING REDUCTION PROCESS



4.0 - STEELMAKING OPERATIONS

4.0 - STEELMAKING OPERATIONS

The standard Argon Oxygen Decarburization (AOD) operation for stainless steel manufacture commences with a heat of steel that generally analyzes up to 0.5 percent silicon and 1.0 percent carbon. Blowing practices have been developed that reduce the carbon to levels as low as 0.02 percent using combinations of oxygen, argon and nitrogen. The silicon will be removed at the same time. The oxidation of carbon and silicon generates heat that typically raises the metal bath temperature between 200 and 400^{o}F and enables the operator to charge scrap as coolant during the steelmaking operation.

The molten iron-chrome-nickel alloy that could be produced from the chromite concentrates and Sherritt Gordon tailings in the submerged arc furnace will contain up to seven percent carbon and one percent silicon. While these carbon and silicon levels are substantially higher than those that commonly occur in a scrap-based AOD charge, similar operations do exist. At the Hachinohe Works of Pacific Metals in Japan, an LD converter is supplied with a molten alloy containing 3.5 to 4.5 percent carbon and 1.5 to 2.5 percent silicon. This molten alloy is a mix of high carbon ferronickel and high carbon ferrochrome which is blown to 3 percent carbon and 0.2 percent silicon before being transferred to an AOD which operates only with side tuyeres. At Krupp in West Germany, an alloy containing up to 2.5 percent carbon is the transfer metal from an electric furnace to the AOD vessel.

The steelmaking process for Manitoba must recognize that the oxidation of the high levels of carbon and silicon will generate higher than normal vessel temperatures and that there will be minimum scrap available as coolant. The proposed processing concept includes a Q-BOP, a bottom blown steelmaking vessel, followed by a conventional side blown AOD vessel. Bottom blowing in the Q-BOP ensures high oxygen usage efficiency

and low post-combustion in the freeboard of the vessel. Combined with a close fitting hood to collect the off-gas, temperatures are expected to be controllable.

As shown by the calculations in Appendix III, the method suggested to control heat release in the Q-BOP is by using oxygen-enriched air rather than commercial purity oxygen. The nitrogen component of the air therefore becomes the carrier medium for removal of heat from the vessel. The Q-BOP tuyeres for a 50 tonne vessel are capable of delivering 7,000 SCFM of gases to the steel bath. Using 77 percent clean and dry air together with 23 percent commercial purity oxygen, a 39 percent oxygen gas into the Q-BOP will provide both the means for carbon removal as well as the mechanism for heat removal. The turnaround time on the Q-BOP vessel is shown to be 60 minutes, of which 38 minutes is blowing time.

At the end of the Q-BOP blow, the steel bath has been calculated to analyze 1.1 percent carbon and zero silicon and be at a temperature of 3,200^{o}F. During transfer from the Q-BOP to the AOD, the steel bath will lose heat such that at the start of the AOD operation, a temperature of about 3,000^{o}F should be achievable. A 45 minute AOD cycle has been developed as shown in Appendix III and bath temperature will be controlled by additions of nickel, with manganese and silicon alloys added late in the cycle for correction to specifications. At this time, only argon has been included as the purge gas in the AOD even though nitrogen is used on a regular basis in scrap based steelmaking shops. This decision has been made because of the large quantities of air that have already been utilized in the Q-BOP operation which could lead to high nitrogen levels in the steel.

4.1 - Steelmaking Costs

The cost of the steelmaking operation has been developed from the raw material usage data given in Appendix III and some commonly accepted unit

prices prevailing at the present time in the industry. Labor and supplies costs have been taken from Hatch Associates' May, 1987 report.

As detailed in Table 4.1, the total direct cost of producing 186,000 tonnes of 304 stainless steel as hot metal is shown to be $265,923,600 or $1,430 per tonne. The dominant cost components are the submerged arc furnace metal and the nickel. The furnace metal costs might still be lowered although perhaps not too significantly. Nickel has been assigned the current LME cash price, as discussed in Section 2.0 of this report, which is presently about $6 (Canadian) per pound. Evidently, nickel prices significantly effect the cost of producing the Type 304 stainless steel. However, as also demonstrated by the pricing practices described in Section 2.0, this cost has in recent times generally been passed on directly to the consumer and therefore is not as critical a factor as might first appear. Other steelmaking raw materials include ferrosilicon, silicomanganese, lime and fluorspar which total over $10 million annually. Process gases include oxygen, argon and dry compressed air with a total annual cost of over $7 million. Depending on the chemistry of the product, it may be possible to switch some of the argon for less expensive nitrogen or even dry compressed air. In summary, the overall operating cost using alternative No. 4 is $1,430 per tonne of hot metal, equivalent to 53 cents (US) per pound of molten Type 304 stainless steel. This cost appears to be competitive with AOD hot metal produced from the scrap based steelmaking route.

For alternative No. 5, which includes a chrome chemicals operation, the cost of producing the stainless steel will decrease by approximately $115 per tonne of type 304 hot metal. This cost decrease is mainly due to the fact that the chromite tailings have been assigned a zero value, which is justifiable at present from the chrome chemicals operation viewpoint since tailings disposal is a significant cost under normal circumstances.

The steelmaking operation does require more Class I nickel under alternative No. 5 to compensate for the lesser quantity of nickel entering the process with the Sherritt Gordon tailings. With all of the alternatives, recycle of scrap constitutes a closed-loop concept and as such only new raw materials have been identified.

TABLE 4.1

STEELMAKING COSTS

Basis: $(Canadian) to Produce 186,000 Tonnes of 304 Hot Metal

COMPONENT	ANNUAL REQUIREMENT	UNIT PRICE	TOTAL COST
Submerged Arc Furnace Metal	188,000 tonnes	$430.45/tonne	$ 80,924,600
Nickel - Class I	12,130 tonnes	$6.00/pound	160,407,000
50% Ferrosilicon	6,360 tonnes	$1,000/tonne	6,360,000
Silicomanganese	2,670 tonnes	$650/tonne	1,735,500
Lime	8,460 tonnes	$220/tonne	1,861,000
Fluorspar	850 tonnes	$550/tonne	467,500
Oxygen	$1,203 \times 10^6$ SCF	$0.25/100 SCF	3,007,500
Argon	93×10^6 SCF	$3.50/100 SCF	3,255,000
Dry Compressed Air	843×10^6 SCF	$0.10/100 SCF	843,000
Operating and Maintenance Labor			2,062,500
Maintenance Supplies, Miscellaneous Supplies and Services			5,000,000
	TOTAL DIRECT COSTS		$265,923,600

Equivalent to $1,430 per tonne of hot metal.

5.0 - SLAB CASTING AND HOT ROLLING MILL OPERATIONS

5.0 - SLAB CASTING AND HOT ROLLING MILL OPERATIONS

Cold rolled stainless steel sheet needs to have a surface free of irregularities, be without internal voids and inclusions and have reproducible mechanical properties. In standard practice, these requirements are achieved by casting slabs, conditioning the surfaces to remove blemishes, rolling to hot band, pickling, cold rolling and annealing. The high reduction in thickness from slab to hot band results in high levels of internal soundness and good mechanical properties. All of the large tonnage stainless steel producers in North America operate slab casters and hot strip mills in order to produce hot band either for conversion directly to cold rolled sheet and strip or for sale to other finishing operations. The slabs are generally produced in a range of thicknesses between 125 and 175 millimeters, and this dimension dictates the complexity of the hot strip mill for reduction to the hot band thickness range of 2 to 8 millimeters. Conventional equipment allows for surface conditioning between the caster and the hot strip mill. Visible defects can be ground out before the slab is reheated and rolled to hot band, and this practice ensures minimum rejection rates for hot rolled material.

Despite the success of the established methods for producing a high quality hot band, significant development work has been carried out over the past ten years in thin slab and thin strip casting since these process modifications are perceived as being the means of eliminating processing steps and therefore lowering both capital and operating costs. Thin slab, in this context, is generally defined as having a thickness between 20 and 50 millimeters which can be rolled to hot band in a less complex hot strip mill than is required from conventional slab dimensions. Cast thin strip goes one step further in possibly eliminating entirely the need for a hot mill. Development work in this regard has been carried out on both carbon and stainless steels and Figure 10 gives a tabulation of the experimental techniques and their present status. These developments have been on an international level

but of all the concepts, only SMS-Concast and Danieli have so far supplied commercial units. SMS is furnishing a thin slab caster to Nucor for their Crawfordsville, Indiana, facility which will be a carbon steel operation scheduled for start-up in 1989. Danieli has supplied a thin slab caster to Feng Lung Steel in Taiwan. Mannesmann Demag retrofitted thin slab casting to a production unit on a temporary basis.

The major obstacles to successful implementation of the thin slab or thin strip caster approach are the production rate and the quality requirements for thermo-mechanical processing. Problems that need to be solved are practical refractory methods to convey molten metal from ladle to mold at a controlled rate, techniques to control the inner solidification profile and methods to eliminate edge effects. Both Danieli and Demag employ a special funnel type nozzle that permits metal entry into slit type molds of a conventional design. SMS on the other hand utilizes an ogival shaped mold which allows a conventional nozzle entry at the top. The thermal shrinkage of the skin is followed by the mold during casting and the ogival shape is taken out at about the 65 percent position down the mold, producing a 50 millimeter by 1.0 meter slab shape. The SMS approach to casting is known to produce a good surface quality in carbon steels while the results of Danieli and Demag are not available for review at the present time.

5.1 - Process Considerations

Within the mold, the interfacial resistance to heat transfer between the cooled substrate and the steel shell controls and also limits heat removal and therefore progress toward solidification. The solidified skin thickness may be represented by equation

$$T = kt^{0.5}$$

where T is the solidified thickness, t is time and k is a constant. Experimental data from two different companies on twin roll casting of type 304 stainless steel is shown in Figure 11 to be mutually consistent

over a range of thicknesses from 0.2 to 12 millimeters. The data has also been shown as consistent with an interfacially controlled heat transfer mechanism and also confirms that rapid solidification does not occur. As solidification proceeds, the rate of advance of the solid interface slows and the grain size increases. Consequently, even the thinnest material that has been cast in a twin roll machine had cross sections of variable grain size with coarser grains at the center, together with centerline voids and shrinkage cavities. Even for thicknesses down to 0.15 millimeters, all the conventional solidification defects existed.

For a given production rate and slab width, casting speed must increase linearly as thickness decreases. For example, a 250 millimeter thick slab with a casting speed of 0.025 meters per second would produce equivalent quantities to a 2.5 millimeter strip with a casting speed of 0.25 meters per second. The 250 millimeter thick slab might have a solidification time of 25 minutes, resulting in a casting machine length of 37.5 meters in order to restrain the solidifying slab from bulging on its wide faces. Conversely, the solidification time for a 2.5 millimeter strip would be approximately 0.53 seconds using a two sided casting process, implying a machine length of only 1.4 meters. In a slab caster, the solidifying skin in the mold is thick enough to be transferred to a secondary roll containment system without rupture after a mold residence time of 15 to 35 seconds. In strip casting, however, solidification must be complete within the mold and the casting machine length is the same as the mold length. It has been this potential opportunity of manufacturing a caster that is only 5 to 10 percent of the length of a regular slab caster that has prompted the efforts towards commercialization of thin slab and thin strip casting, even though the full solidification process must occur in the mold.

With respect to surface quality, both entrained oxides and surface irregularities present more problems in strip casting. In conventional slab casting, oxide entrainment can be minimized by utilizing protective

refractory shrouds between the ladle and the tundish, non-reactive refractories and oxide-absorbing covering slag on the tundish, and refractory shrouds between the tundish and the mold. The tundish-to-mold shroud itself operates with its lower end submerged in the metal of the mold. The flow from the tundish to the mold is directed preferentially by ports in the lower end of the shroud so as to control turbulence in the mold pool. The mold is oscillated sinusoidially and a molten oxide-fluoride slag lubricates the mold surfaces and absorbs any oxide or spinel inclusions which might have been generated during casting. When producing strip directly, there is, as yet, no pouring system that has been developed for directional steel flow into the mold, and pouring is carried out with an open, unprotected stream. This practice leads to the formation of both oxide and spinel inclusions. The additional problem of the freezing-in of surface laps and folds also occurs, caused by the uncontrolled metal stream creating random turbulence in the mold pool. The waves that are generated, in turn, are frozen into the surface by the relatively high initial heat transfer rates. A cold rolling operation cannot and does not alter the shape of the metal strip other than to decrease its relative thickness and any surface imperfections in directly cast strip cannot be removed and are transferred into the finished product.

A further major problem with strip cast product is the development of mechanical properties. In standard casting practice, the hot rolling that is required to obtain a strip thickness suitable for entry to a cold mill also refines the grain structure and improves the mechanical properties. With direct cast strip, the development of mechanical properties is somewhat more limited, as shown in Table 5.1 which lists results from Allegheny-Ludlum's one-sided planar flow strip casting development. The longitudinal and transverse specimens of the strip have properties inferior to those of conventional 304 and, as cold rolling reductions increase, there is a decrease in the elongation. In order to achieve properties equivalent to conventional 304 stainless steel, the directly cast strip has to undergo a double cold rolling and annealing

cycle. Therefore, metallurgical problems have effectively limited casting developments to the thin slab range thickness of 20 to 50 millimeters.

In order to produce hot band with mechanical properties similar to those of conventionally cast materials, the cast thickness needs to be at least four times that of the hot band. Based on data received during the market survey that was carried out in January, 1988, hot band could range in thickness between 2 and 8 millimeters. Therefore, slab thickness should be in the range of 10 to 30 millimeters. Figure 12 illustrates the ability of a hot strip mill to remove or diminish transverse crown at various thicknesses. Above 12 millimeters, it is possible to remove crown. At 6 millimeters, any attempt to remove crown leads to longitudinal elongation which manifests itself as waves and buckles and does not correct transverse irregularities. As a result of this fundamental rolling mill characteristic, cast product must be perfectly flat in both directions if it is to be directly cast at less than 12 millimeters thick and the technology does not presently exist to satisfy this requirement.

Since the optimum arc for metal contact at the rolls for a twin roll machine has been found to be 30 degrees, wheel diameter effectively limits product thickness. Thus, from a mechanical point of view thin strip in a range of 1.3 to 2.5 millimeters thick can be produced directly on twin roll machines. The present state of commercialization, however, prevents the application of this caster technology for thin slab production. Both a conventional slab caster producing 125 millimeter thick slab operating at a speed of 0.010 meters per second and thin slab in the 25 to 50 millimeter thickness range at a speed of 0.025 to 0.050 meters per second could be used to produce stainless product since these speeds are within the limits of existing technology. The oscillating mold concept for either thin or standard slab is the only technique to date with the potential of producing adequate product quality in the tonnage range required. A commercial thin slab installation being built

for Nucor at Crawfordsville, Indiana, uses this technology and the product will be 50 millimeter thick carbon steel slab in widths ranging from 1000 to 1350 millimeters. It must however be noted that handling of a long thin slab is difficult. In addition, the slab must not be allowed to cool too far because reheating from cold is too problematic.

Since the thin slab will have a very large surface area compared to a standard thickness of slab, heat losses will be high and rolling mill limitations will have a significant effect on the proposed operation. Beyond the obvious constraint that the mill must run when the caster is running, other potential problems are illustrated in Figure 13. Scenarios A and C result in temperature-related mill and product problems. In Scenario B, a planetary rolling mill is thought to lead to poor surface quality. The configuration adopted by SMS who is supplying the Nucor facility is illustrated in Figure 14. In this case, the mill is not directly coupled to the caster but the slab remains hot between processing stages. The 50 millimeter thick slab, after heating in a tunnel furnace, will be accelerated into the mill. The capital cost of the combined caster and mill installation at Nucor has been estimated at about $250 million (US) for a projected capacity of 730,000 tonnes per year. The cost of the four stand continuous mill alone is about $200 million (US), indicating the caster is costing $50 million (US). By the addition of a second casting strand and some mill modifications at a cost of $100 million (US), capacity at Nucor could be increased to 1,350,000 tonnes per annum. These capital costs compare very favorably with a price of $550 million (US) for a conventional 3.0 million tonne per year hot mill and $300 million (US) for a similarly sized conventional twin strand slab caster.

The present concept is to produce 180,000 annual tonnes of hot band in Manitoba from approximately 200,000 annual tonnes of hot metal. The 20,000 tonne difference will be a recycling load of tundish skulls and mill crops. The caster-mill complex therefore receives up to 50 tonnes

of refined hot metal in a ladle every two hours. Assuming a steel-in-mold time of 65 percent, the casting rate would be a maximum of 650 kilograms per minute. In order to minimize the likelihood of breakouts below the mold, the operating parameters must be to the left of the thickness-time relationship as shown in Figure 11. For a slab width of one meter, the parameters for various casters are as shown in Table 5.2.

5.2 - Caster and Mill Operating Costs

The operating cost for a caster-mill complex as a function of capacity is illustrated in Figure 15. The cost of a typical North American caster and hot strip mill facility for carbon steels is approximately $38 (US) per ton for a hot mill, with about $12 of the costs in the roughing and $26 in the finishing operations, with additional slab caster costs of $23 (US) per ton. For a caster and mill arrangement shown in Figure 15 that is capable of producing 800,000 tons per year of product and when the hot mill does not have roughing, reheating costs are less than for the conventional arrangement and the resulting savings are about $8 per ton. However, casting technology is similar to that for a conventional caster, and tundish costs are higher because the technology precludes sequence casting. This penalty, in fact, offsets any mill savings so the operating cost will be about the same. For the thin slab caster-continuous hot mill operation, operating costs will therefore be about $61 (US) per ton at 800,000 tons per year. Extrapolating beyond the curve of Figure 15, the operating cost becomes $150 (US) per ton or $200 (Canadian) per tonne for a production rate of around 180,000 tonnes per year.

The caster mill alternative for Manitoba should allow for the option of inspecting slab surfaces before rolling. The cost of a high product reject rate needs to be carefully considered against the cost of adding a conventional reheat furnace. The advantages of a reversing hot mill, either of Steckel or planetary design, must also be carefully evaluated, but for study purposes the capital costs are not appreciably different.

Planetary mills have been operating in stainless steel mills for many years and, although maintenance costs are higher than in a continuous mill, the operating cost per ton as well as the capital cost are much lower when production levels are low. Allowing an additional $40 (Canadian) per tonne for slab conditioning and $5 per tonne for reheating, the cost of converting liquid steel to hot band has been estimated at $245 (Canadian) per tonne for an output of 180,000 tonnes per year of hot band.

5.3 - Caster and Mill Capital Cost

The capital cost of a 180,000 tonne per year conditioning and reheating facility for slab in the 100 to 175 millimeter thickness range is less than ten percent of the total caster-hot mill installation. If slab conditioning is eliminated in the continuous mill concept, control of product quality may be a problem. In addition, while the length of a 125 to 175 millimeter thick slab is manageable, materials handling of 25 to 50 millimeter thick slab for the same hourly production rate will effectively increase capital costs. While the SMS-Concast installation designed for Nucor at Crawfordsville is adequate for high tonnage carbon steel products, it is not seen as ensuring the high quality requirements demanded of flat rolled stainless steel. Therefore because of quality requirements and the lack of certainty that the overall capital cost would indeed be lower, the proposed flowsheet includes slab conditioning and reheating.

Based on the requirements of operability and minimum capital costs, the preferred arrangement would be a conventional single strand slab caster, a slab yard with conditioning facilities, a slab reheat furnace, a planetary or reversing hot mill and the usual coilers, storage and shipping facilities. The order-of-magnitude capital cost for a one strand slab caster producing 180,000 tonnes per year of 125 millimeter

thickness material in widths up to 1.35 meters is $100 million (Canadian). The hot mill inclusive of conditioning facilities and slab reheating furnace is expected to cost an additional $140 million (Canadian). Therefore the total cost for the slab caster and hot mill facility has been estimated at $240 million (Canadian).

TABLE 5.1

TENSILE PROPERTIES OF STRIP CAST TYPE 304
(REFERENCE: PITLER ET.AL.)

CONDITION	SPECIMEN	0.2% YIELD STRENGTH (MPA)	ULTIMATE STRENGTH (MPA)	ELONGATION (%)
Strip Cast	L	258	599	36.0
1 mm Thick	T	262	585	32.5
Strip cast				
50% CR & Anneal	L	293	671	48.5
0.50 mm Thick	T	297	680	52.0
Conventional 304	L	293	671	56.8
0.50 mm Thick	T	331	700	54.0
Strip Cast				
65% CR & Anneal	L	305	685	52.0
0.33 mm Thick	T	312	664	56.0
Strip Cast				
75% CR & Anneal	L	330	703	48.5
0.25 mm Thick	T	316	705	65.5
Conventional 304	L	299	686	57.4
0.25 mm Thick	T	301	670	62.7
Strip Cast				
50% CR & Anneal	L	295	700	63.0
0.25 mm Thick	T	286	687	60.0

Anneal - 1120°C for 1 Minute- Followed By A Water Quench

Table 5.2

MACHINE PARAMETERS

Casting Rate : 650 kilograms per minute
Slab Width : 1,000 millimeters

Slab/Strip Thickness (mm)	Caster Speed (meters/sec)	Time To Solidify (seconds)	Required Roll Diameter (meters)	Comments
1.3	0.96	0.16	0.56	Twin Roll, One Strand
2.50	0.50	0.52	1.00	Twin Roll, One Strand
10.0	0.12	6.4	2.93	Twin Roll One Strand
25.0	0.050	33.1	6.44	Twin Roll, Thin Slab, One Strand
50.0	0.025	58.0	N/A	Thin Slab One Strand
125.0	0.010	375.0	N/A	Standard Caster, One Strand

FIGURE 10 :

NEAR NET SHAPE CASTING PROCESS

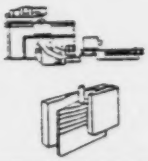
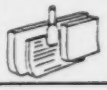
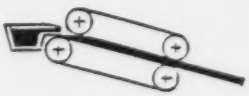
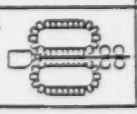
Process	Manufacturer/ operator	Technical data	Product
Stationary mould 	SMS Buschhutten	Thickn.: 40–60 mm Width: 1600 mm v_G: 6 m/min 750,000 t/a	Thin slab
	SMS/Nucor Corp. Crawfordsville (Il. 1989)		Usual hot strip grades
Stationary mould 	MDH/MRW Huckingen	Thickn.: 40–70 mm Width: 1600 mm v_G: 6 m/min	Thin slab Usual hot strip grades
Stationary mould	Danieli Udine	Thi.: 28 50 mm Wi.: 1600–1750 mm v_G: 6 m/min	Thin slab Strip
	Danieli Feng Lung Steel Factory Taiwan	Thickness: 75 mm Width: 1220 mm	Thin slab
Stationary mould in horizontal line HCC	MDH/Bosch-gotthardshutte Siegen	Thickn.: 40–120 mm Width: 450 mm v_G: 4 m/min 100,000 t/a	Thin slab All steel grades
Mould car	British Steel Corp. Teesside Labs	Thickness: 75 mm Width: 500 mm v_G: 10–20 m/min	Thin slab Plain carbon steel
2 travelling belt moulds, vertical	Nippon Steel Corp.	Thickness: 50–80 mm Width: 600 mm v_G: 4 m/min	Thin slab
2 travelling belt moulds, horizontal KCC = Kawasaki Horizontal Continuous Caster	Kawasaki Steel Corp. Chiba Research Centre	Thickness: 10–30 mm Width: 100–150 mm v_G: 0.7–12.5 m/min	Strip Low-carbon steels Si-steels Stainless steels
2 travelling belt moulds, inclined  Hazelett	Hazelett/ Sumitomo MI+ Sumitomo HI Kashima	Thickness: 40 mm Width: 600–1300 mm v_G: 2–8 m/min 600,000 t/a (1300 mm)	Thin slab Al-killed steels Stainless steels
	Hazelett/ Nucor Corp. Darlington, S.C.	Thickness: 25–38 mm Width: 1300 mm v_G: 1.5–8 m/min 500 000 t/a (1300 mm)	Strip Carbon steels
	Hazelett/ Krupp Industrietechnik Bochum	Thickness: 70 mm Width: 180 mm abandoned	Thin slab
	Hazelett/ Bethlehem Steel + US Steel Universal, Pa.	Thickness: 12–25 mm Width: 1830 mm interrupted/abandoned	Strip
2 travelling caterpillar moulds, horizontal 	Kobe Steel Nippon Kokan	no details known	

FIGURE 10 CONTINUED :

NEAR NET SHAPE CASTING PROCESS

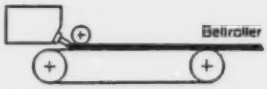
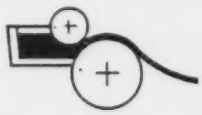
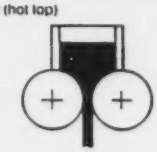
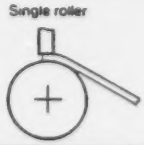
Process	Manufacturer/ operator	Technical data	Product
1 travelling casting belt and 1 roller  DeSC-Process Demag Strip Casting	MDH/MSA Belo Horizonte (1988)	Thickness: 5–10 mm Width: 900 mm v_G: 25–50 m/min 750.000 t/a	Strip All steel grades
Inside-The-Ring	Jones + Laughlin (now LTV Steel) Pittsburgh (1967–1975)	Thickness: 5 mm Width: 380 mm v_G: 7.5 m/min	Strip
Twin roller (top roller) 	Kobe Steel Amagasaki	Thickness: 1–2 mm Width: 260 mm	Thin strip Stainless steels
	Nippon Metal	Thickness: 1–4 mm Width: 315/650 mm	Thin strip Stainless steels
	Krupp Stahl AG	Thickness: 1–4 mm Width:	Thin strip Stainless steels
	Nippon Yakin	Thickness: 6 mm Width: 150 mm	Strip Stainless steels
Twin roller (hot top) 	Ishihari HI/ Nippon Kokan	Thickness: 2–6 mm Width: 400 mm v_G: 25 m/min	Strip Thin strip Carbon steels Stainless steels
	Hitachi Zosen Corp.	Thickness: 5–10 mm Width: 300 mm	Strip
Twin roller	Nippon Steel Corp.	Thickness: 1 mm Width: 200 mm	Thin strip Stainless steels
	Nisshin Steel + Hitachi Corp.	Thickness: < 5 mm Width: 200 mm	Thin strip Stainless steels
	Kawasaki Steel Corp.	Thickness: 0.5 mm Width: 100 mm	Thin strip St-steels
	Armco + Inland Steel + Weirton Steel + Bethlehem Steel	Thickness: < 5 mm Width: 300 mm	Thin strip
	Clecim/Irsid	Thickness: 2–10 mm Width: 200 + 850 mm	Strip Thin strip Stainless steels
	DEC/British Steel Corp	Thickness: 3 mm Width: 400 mm	Thin strip Stainless steels
	CSM	Thickness: Width: 300 mm	Thin strip Unalloyed steels
	Voest-Alpine	Thickness: 2–8 mm Width:	Strip Thin strip
	Thyssen Grillo Funke + IBF Aachen	Thickness: 0.1–2 mm Width: 150 mm	Thin strip St-steels
	MPI fur Eisenforschung Dusseldorf	Thickness: 1 mm Width: 100 mm	Thin strip St-steels
Single roller 	Armco + Weslinghouse Middletown	Thickness: 0.8–3 mm Width: 75 mm	Thin strip
	Allegheny Ludlum	Thickness: 1–2 mm Width: 300 mm	Thin strip Stainless steels

FIGURE 11 :

SOLIDIFICATION TIME AS A FUNCTION OF CAST THICKNESS

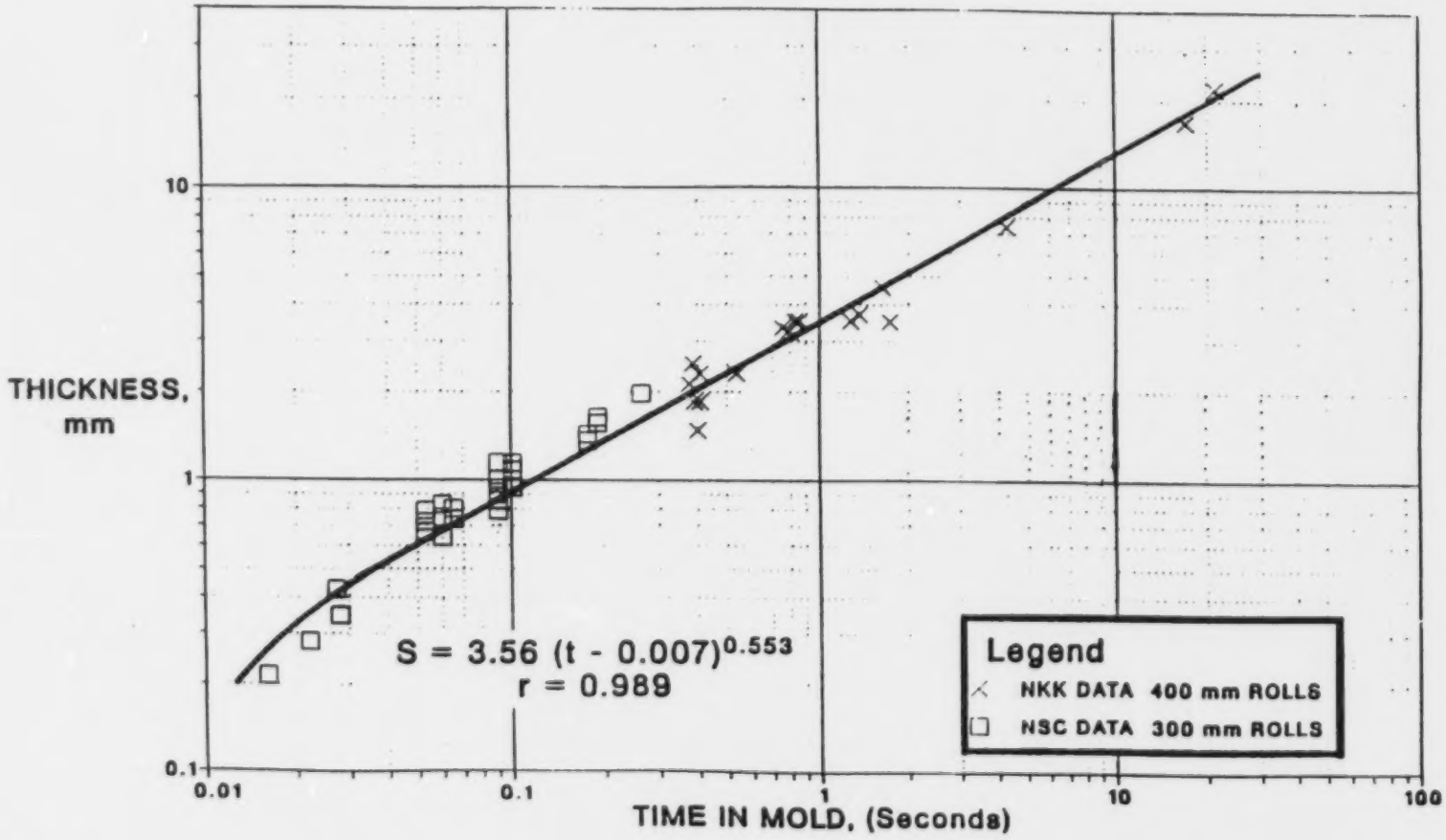


FIGURE 12 :

MATERIAL FLOW DURING STRIP PROFILE CORRECTION

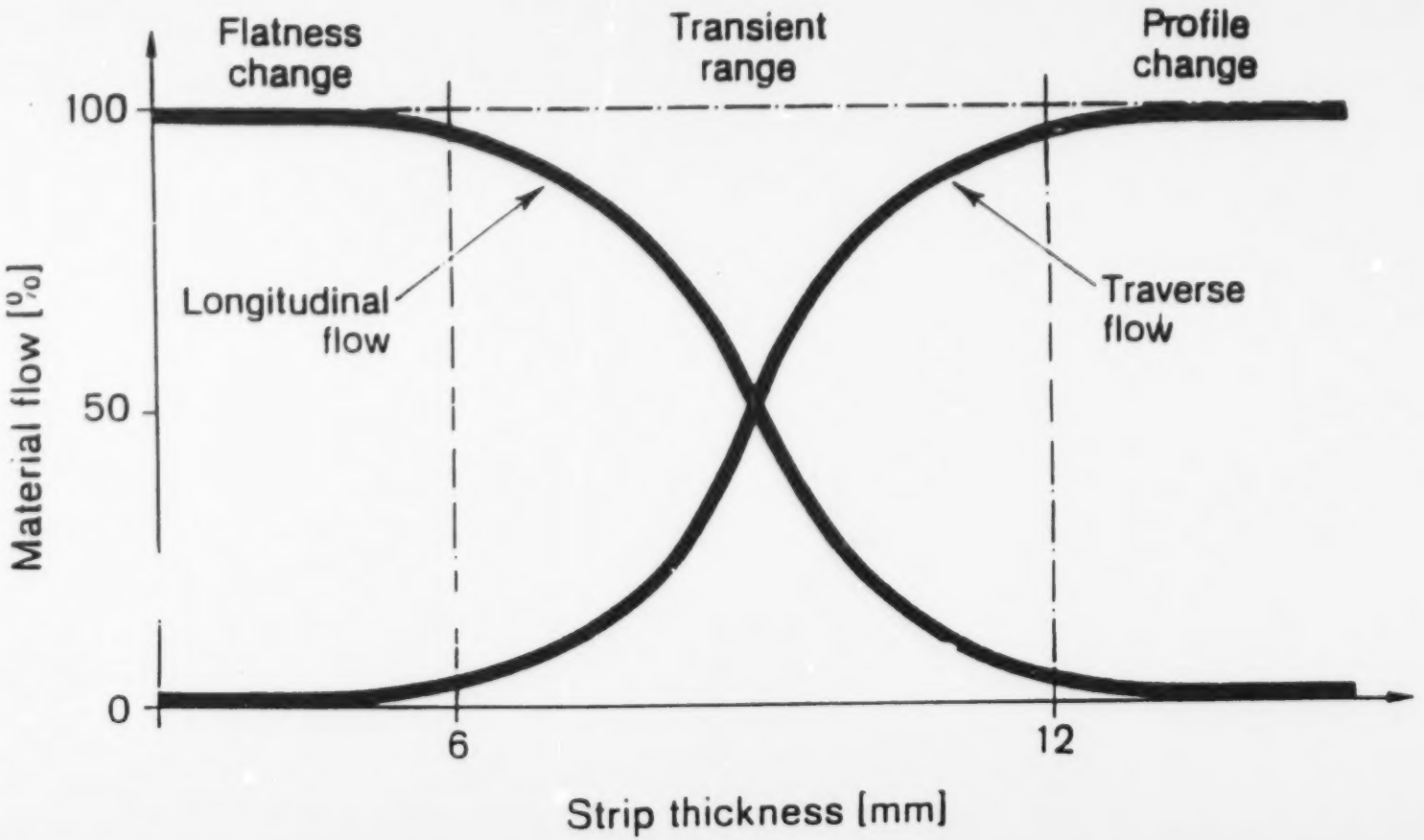


FIGURE 13 :

MILL CONSTRAINTS WHEN CASTING THIN SLABS

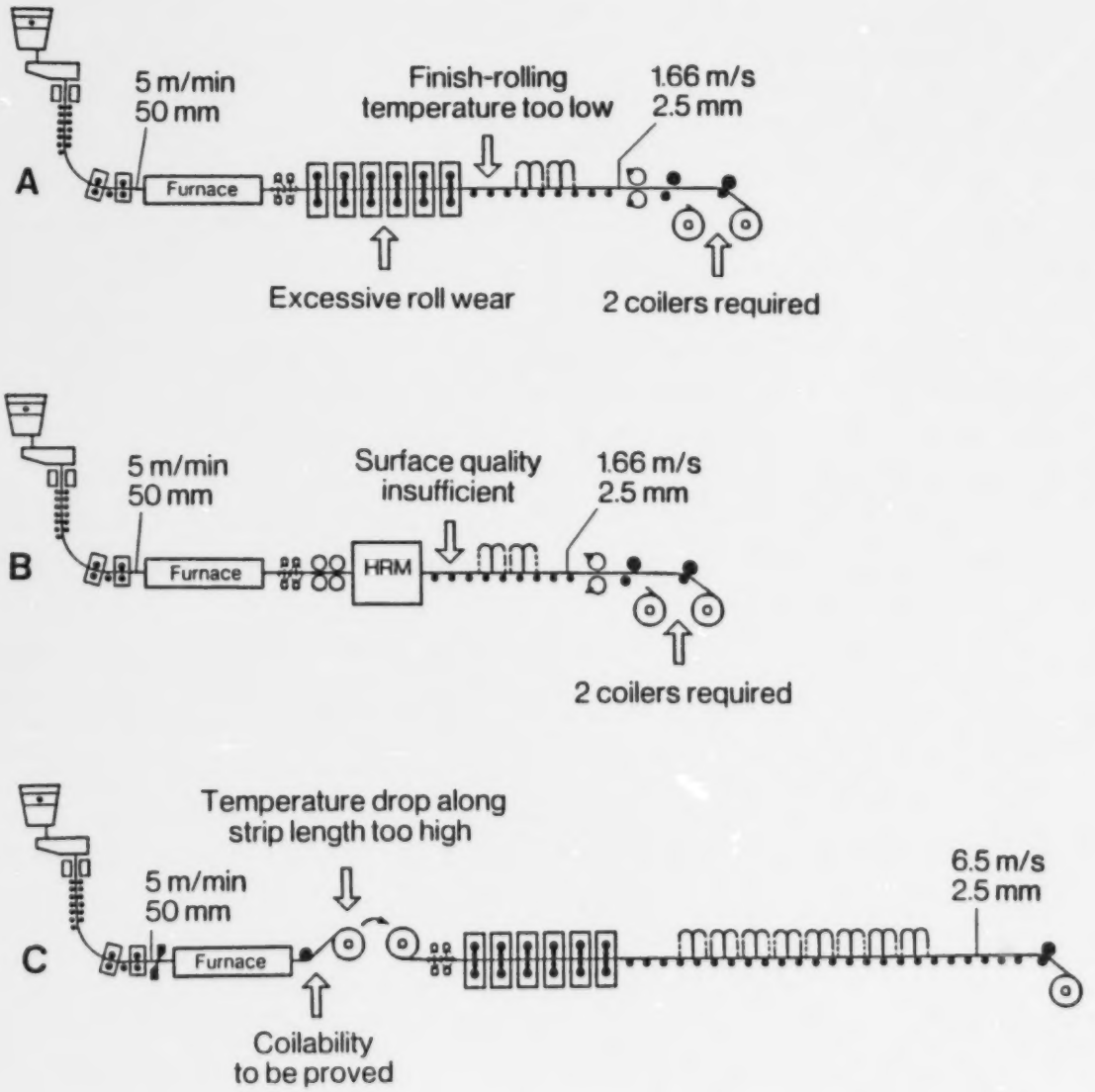
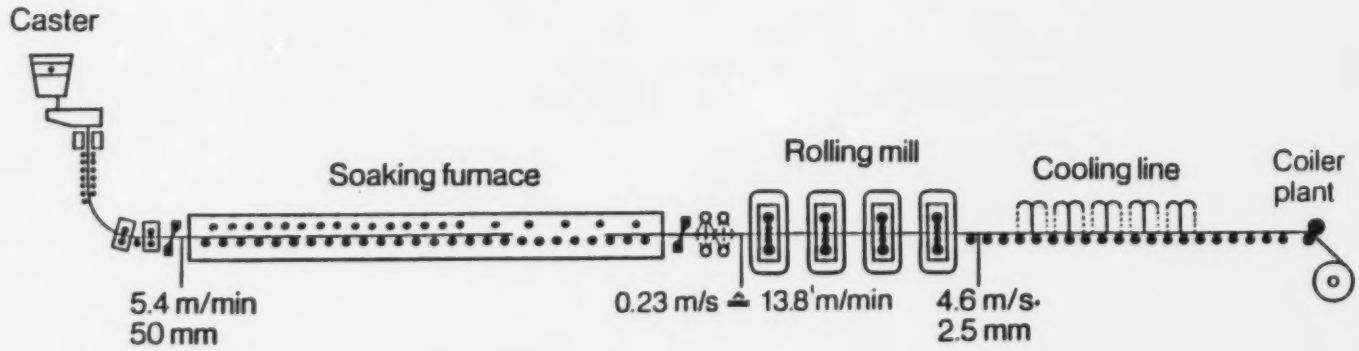


FIGURE 14 :

CONFIGURATION OF A COMMERICAL THIN SLAB CASTER



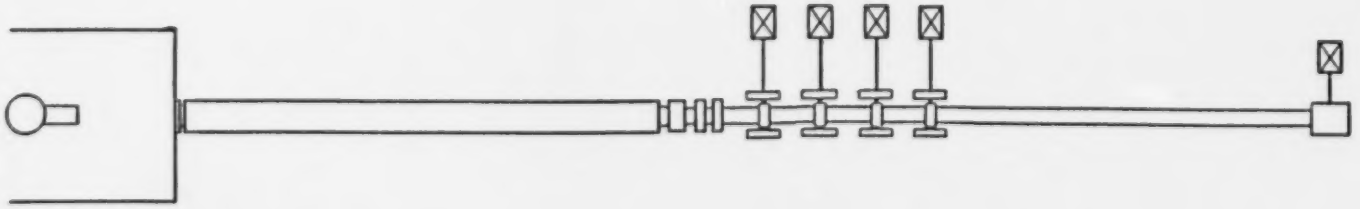
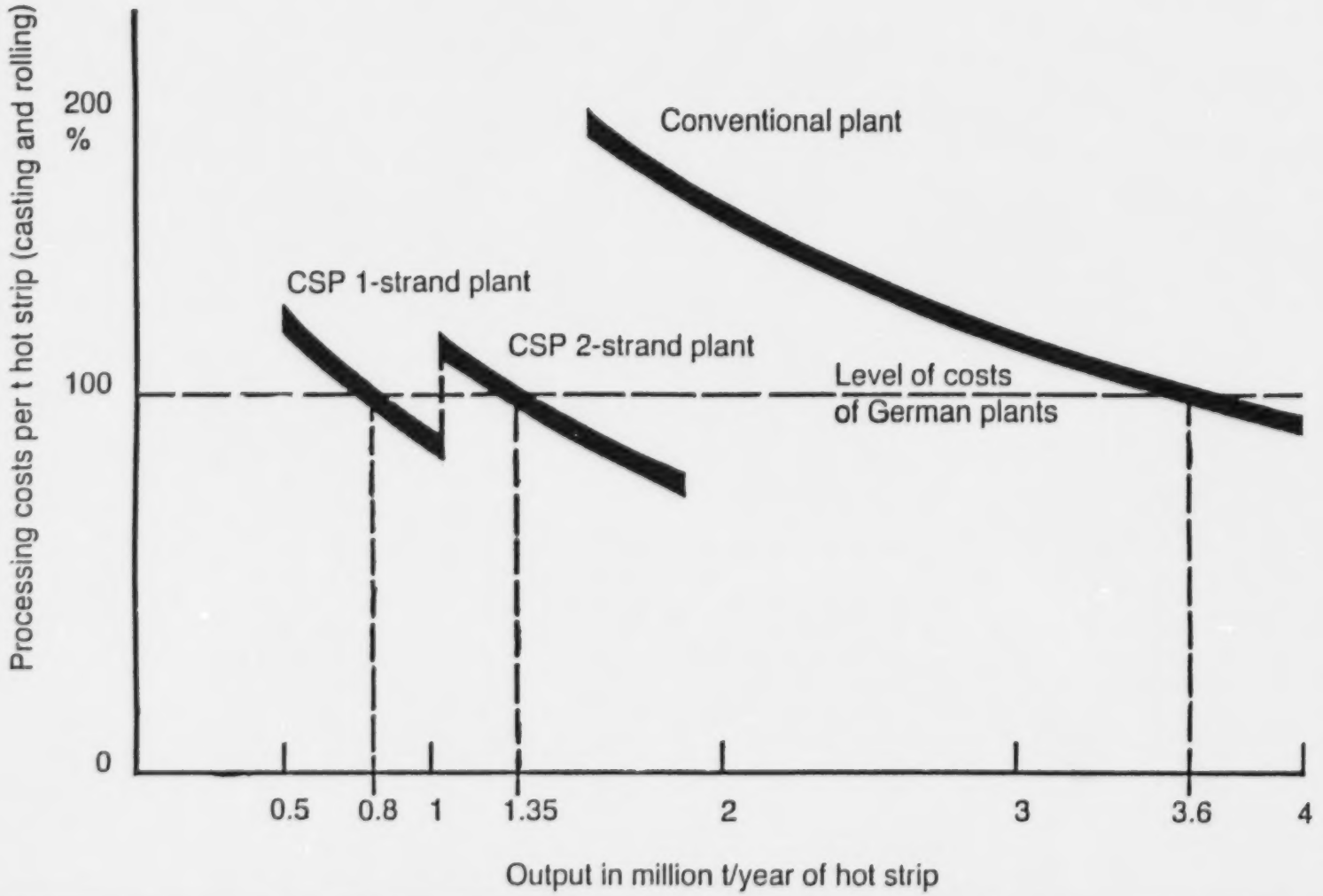


FIGURE 15 :

OPERATING COSTS FOR CASTER - MILL COMBINATIONS



6.0 - OPTIMIZED FLOWSHEETS AND COSTS

6.0 - OPTIMIZED FLOWSHEETS AND COSTS

The process flowsheet for hot band manufacture in Manitoba has been redefined primarily as a result of the availability of iron-nickel tailings from Sherritt Gordon. This material eliminates the need for steel scrap and reduces the quantity of Class I nickel that is needed in the manufacture of 304 stainless steel. The alternative of the chrome chemicals operation is still an option although its inclusion raises the quantity of Class I nickel that will be needed for the steelmaking process, as well as increasing the capital costs. In either case, there is evidently no need for the magnetic concentrates that could be produced from the concentrate tailings, provided the Sherritt Gordon tailings are competitively priced for both nickel and iron units.

6.1 - Type 304 Stainless Steel Operation

The Type 304 stainless steel operation envisioned for Manitoba as shown in Figure 16 includes pelletization of the chromite concentrates with iron and nickel oxide tailings from Sherritt Gordon, followed by smelting in two 32MW submerged arc furnaces. The molten iron-chrome-nickel alloy is fed to a 50 tonne Q-BOP steelmaking vessel where the carbon is blown down from seven (7) to one (1) percent. This one (1) percent carbon steel is then transferred to a 50 tonne AOD and the nickel is added at this time, together with other alloying additions. The finished 304 stainless steel is then cast into slabs, and rolled down to hot band. The metal analyses at each of the three major steelmaking stages are given in Table 6.1. The chromium units all originate from the chromite concentrates while nickel is added mainly at the AOD refining stage.

As had been shown previously in Table 4.1, the direct operating cost would be $1,430 (Canadian) per tonne of 304 hot metal. Since there will be a seven (7) percent scrap recycling load that is utilizing excess heat in the Q-BOP, each tonne of hot metal will become a tonne of hot band. The cost of converting hot metal into hot band has been shown in Section

5.2 to be $245 (Canadian) per tonne. Therefore the total direct operating cost becomes $1,675 (Canadian) per tonne of Type 304 stainless hot band, equivalent to 62 cents (US) per pound of hot band.

A summary of typical capital costs expected from a project of this magnitude is shown in Table 6.2. Some of the costs were developed during the Phase III study and updated based on changes to the steelmaking process. For example, pelletizer capacity has been doubled. Steelmaking costs are now based on a Q-BOP/AOD operation. The previous $300 million (Canadian) estimate has been increased primarily because of the expansion in product processing from slab to hot band.

6.2 - Integrated Chrome Chemicals and Type 304 Stainless Steel Operation

An expansion in the scope of the steelmaking process has been developed and proposed in Hatch Associates' March, 1988, report in which the tailings from a chrome chemicals operation becomes the chromium source for the steelmaking facility. This chrome chemicals option has been incorporated into the basic flowsheet as shown in Figure 17. The nickel content of the molten iron-chrome-nickel alloy is somewhat lower than that shown in Table 6.1. The cost of the iron-chrome-nickel alloy is $328 (Canadian) per tonne and molten 304 stainless tapped from the AOD has been calculated to cost $1,345 (Canadian) per tonne as described in Appendix IV. Therefore the total direct operating cost becomes $1,590 (Canadian) per tonne of 304 stainless steel hot band when including the chrome chemicals alternative, equivalent to 59 cents (US) per pound of hot band. This alternative therefore offers the opportunity for a 3 cent per pound or 5 percent cost savings in the steelmaking operation.

A summary of expected capital costs when including the chrome chemicals option is shown in Table 6.3. The increased mine and concentrator capacity allows for the production of 45,000 annual tonnes of sodium dichromate dihydrate crystals as well as 180,000 annual tonnes of Type

304 stainless steel hot band. The total capital cost for this integrated approach is shown to be $490 million (Canadian), a nine (9) percent increase over the stainless steel option alone.

Table 6.1

METAL ANALYSES

	Cr (%)	Ni (%)	Si (%)	C (%)	Fe (%)
Molten Iron-Chrome-Nickel Alloy from submerged arc furnaces	18.6	1.5	1.0	7.0	71.8
One (1) percent Carbon Steel from Q-BOP Vessel	20.0	1.6	-0-	1.1	77.2
Molten 304 Stainless Steel from AOD Vessel	18.0	8.0	0.6	0.06	72.3

Table 6.2

CAPITAL COST SUMMARY

180,000 TONNES PER YEAR TYPE 304 STAINLESS STEEL HOT BAND

	$ Million (Canadian)
Open Pit Mine	35
Concentrator	13
Pelletizing and Sintering	20
Smelter	60
Steelmaking	80
Slab Caster	100
Hot Strip Mill	140
TOTAL	$448
	Say $450 Million (Canadian)

Table 6.3

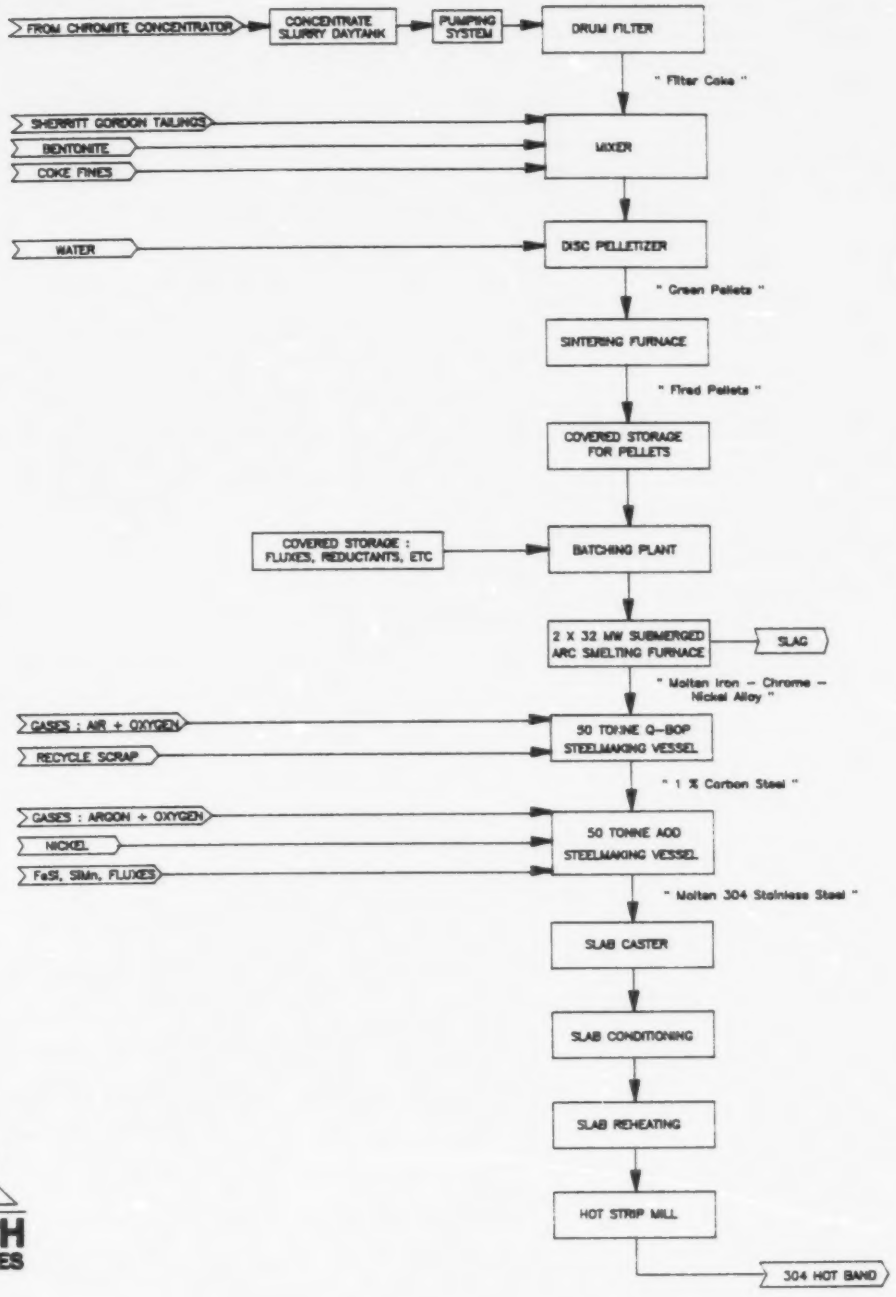
CAPITAL COST SUMMARY

45,000 TONNES PER YEAR SODIUM DICHROMATE DIHYDRATE CRYSTALS

AND 180,000 TONNES PER YEAR TYPE 304 STAINLESS STEEL HOT BAND

	$ Million (Canadian)
Open Pit Mine	44
Concentrator	16
Pelletizing and Sintering	20
Smelter	60
Steelmaking	80
Slab Caster	100
Hot Strip Mill	140
TOTAL	$490

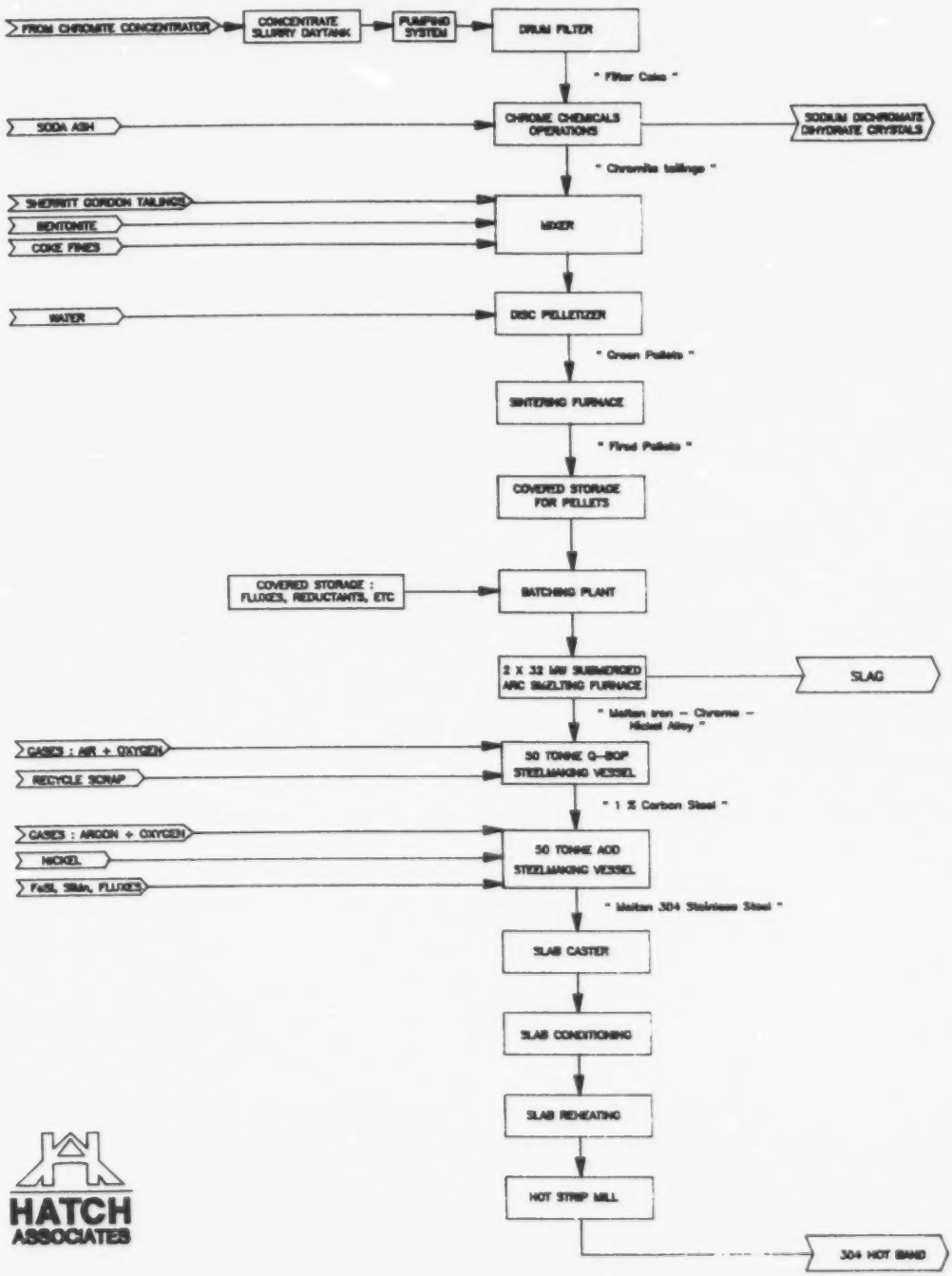
FIGURE 16 :
STAINLESS STEEL PRODUCTION IN MANITOBA
PROCESS FLOWSHEET : FILTER CAKE TO TYPE 304 HOT BAND



HATCH ASSOCIATES

FIGURE 17 :
INTEGRATED CHROME CHEMICALS AND STAINLESS STEEL PRODUCTION IN MANITOBA

PROCESS FLOWSHEET :
FILTER CAKE TO SODIUM DICHROMATE DIHYDRATE CRYSTALS AND TYPE 304 HOT BAND



HATCH ASSOCIATES

7.0 - DISCUSSION AND CONCLUSIONS

7.0 - DISCUSSION AND CONCLUSIONS

The flat rolled stainless steel industry has been operating at full capacity for the past twelve months. During this time, nickel has been in short supply and its price has climbed to record high levels. Chromium prices have also risen substantially with the result that the price for type 304 stainless steel has risen from around $1.50 (US) to over $2.00 (US) per pound during the year. Much of the price increase has been implemented as a raw material surcharge which will theoretically disappear if nickel returns to $2.00 (US) per pound and chromium to 40 cents (US) per pound.

The present high level of demand for stainless steel has complicated the purchasing arrangements of the stainless steel finishing mills that do not operate their own meltshops. Both Mercury Stainless and Coshocton Stainless, two major finishing mills, moved to solve their material supply problems. Mercury Stainless agreed in August to purchase the assets of Washington Steel for $290 million (US) and the deal was closed in October, 1988. Washington Steel will not, however, be able to satisfy the total needs of Mercury's Massillon facility. In July, 1988, the sale of Eastern Stainless Steel in Baltimore, Maryland to Cyclops Industries was approved at a transaction price of $53 million (US). Cyclops plans to increase plate production but also to restart the shuttered sheet facilities. Eastern Stainless does not have a hot mill and therefore slab would have to be converted to hot band at Cyclop's Empire-Detroit operation in Mansfield, Ohio. This hot band could then be finished at Coshocton Stainless in Coshocton, Ohio, or at Eastern Stainless in Baltimore. As shown in Table 7.1 which has been taken from Hatch Associates' March, 1988, report, Coshocton Stainless, Mercury Stainless and Washington Steel accounted for about 60 percent of projected 1992 purchases of hot band. In addition, Sammi Steel of South Korea has entered into an agreement to finish the hot band from POSCO's new stainless melt shop that will commence operations in 1989. Details on

recent telephone contacts have been included in Appendix V. The overall demand for hot band has been reconfirmed but destinations appear to be a little different. For example, Mercury's demand may be lower but Mexinox has a capacity expansion program and Avesta is looking for additional material. Therefore the interest of these and other companies needs to be reassessed in light of recent market developments.

The steelmaking process has been redefined to include two smelting furnaces, Q-BOP and AOD steelmaking vessels followed by a regular slab caster and hot strip mill. The capital cost for this entire process including mine and concentrator has been estimated at $450 Million (Canadian). The option to include a chrome chemicals operation into the process flowsheet will result in an increase in the capital cost to $490 Million (Canadian). The major capital expenditures have been identified in the areas of steelmaking, casting and the hot mill but there should be a potential opportunity to utilize used equipment, and in this way decrease the overall capital cost.

The direct operating cost to produce Type 304 stainless steel hot band will be a variable depending primarily on the cost of nickel. At an annual production level of 180,000 tonnes and using a nickel price of $6 (Canadian) per pound, the direct operating cost for Type 304 hot band from Manitoba is shown to be between $1,590 and $1,675 (Canadian) per tonne, equivalent to 59 to 62 cents (US) per pound. The capitalization of $450 to $490 Million (Canadian) over a 20 year period would be roughly equivalent to between 7 and 10 cents (US) per pound of hot band. Therefore, with some contingency, the total cost of producing 304 stainless steel hot band in Manitoba is expected to cost less than 75 cents (US) per pound when nickel is priced at $6 (Canadian) per pound. Since Type 304 stainless steel hot band under these market conditions is selling for 85 to 95 cents (US) per pound, and allowing for freight equalization to Pittsburgh, the potential annual profit may be projected at somewhere in excess of $20 Million (US) possibly as high as $60 Million (US). Evidently, inclusion of the chrome chemicals option will

increase profits from the steelmaking operation while introducing additional profits from the sale of sodium dichromate dihydrate crystals. A two product operation will also provide an opportunity to shift production levels as market conditions change.

The total energy requirement for a plant of this size expressed as an electric power equivalent is considered to be in the order of 100 MW as shown in Table 7.2. Off-site production of steel plant gases (oxygen and argon) and ferrosilicon, which account for about 16 percent of the total power demand, could be incorporated into the project or become stand-alone industries. Ferrosilicon production capacity could of course be greater if the needs of Manitoba Rolling Mills in Selkirk could be included as well those for the proposed stainless steel plant.

Table 7.1

PURCHASERS OF STAINLESS HOT BAND

Company	1987 Purchases (tonnes)	Projected 1992 Purchases (tonnes)	Preferred Steel Grades (series)	Preferred Sizes/Weights Thickness (mm)	Width (metres)	Weight (tonnes)
Coshocton Stainless, Cyclops	80,000	100,000	300 & 400	4	1.3	18
Mercury Stainless	50,000	110,000	300 & 400	2-4	0.9-1.5	23
Mexinox, Mexico	40,000	40,000	300 & 400	3.5-6	0.9-1.3	15
Sammi Steel, South Korea	135,000	135,000	300	N/A	N/A	N/A
Washington Steel	NIL	100,000	300	2-8	1.0-1.5	N/A
	305,000	485,000				

Source: Hatch Associates' March, 1988 Report for Phase IV-A

Table 7.2

ENERGY REQUIREMENTS FOR 180,000 TONNE PER YEAR

STAINLESS STEEL FACILITY IN MANITOBA

	Equivalent Installed Electric Power (MW)
Smelting Furnaces	64
Concentrator, Smelter Auxiliaries, Steelplant, Caster and Hot Mill	21
Steelplant Gas Production	4
Ferrosilicon Production	12
TOTAL	100

8.0 - RECOMMENDATIONS

8.0 - RECOMMENDATIONS

The major technical issues to be resolved for the stainless steel project in Manitoba are a comprehensive understanding of the geology and potential reserves of the chromite deposit in the Bird River sill and the performance of the concentrates during an oxidation roast to produce sodium dichromate. The geology of the various Bird River deposits has been addressed separately and a drilling program will be identified and presented to the owners of the properties in the near future. The chrome chemicals option needs to be evaluated first on a bench scale using concentrates produced during the Phase II work at Lakefield Research. This investigative activity would provide CANMET with the technical guidelines for development of a pilot plant operation that should be intended to produce concentrates, followed by roasting and smelting, and then converting the high carbon iron into stainless steel.

In recent discussions with stainless steel industry representatives, an original premise was reconfirmed that there is a continuing need to assess the potential market for hot band and to encourage industry co-operation. Without this follow-up activity, the project will lose momentum. The following activities are therefore recommended:

(i) Complete bench scale tests to determine the feasibility of incorporating the chrome chemicals option into the overall project and reassess the economics.

(ii) Complete the exploration drilling programs to confirm a 20 year mine life and again reassess project economics.

(iii) Maintain contact with selected stainless steel companies and inform them of progress on the project. Attempt to identify potential investors who would be prepared to become financially involved for the pilot plant stage.